Nelson

Test Wells, Topagoruk Area, Alaska

EXPLORATION OF NAVAL PETROLEUM RESERVE NO. 4 AND ADJACENT AREAS, NORTHERN ALASKA, 1944–53

PART 5, SUBSURFACE GEOLOGY AND ENGINEERING DATA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 305–D

Prepared and published at the request of and in cooperation with the U. S. Department of the Navy, Office of Naval Petroleum and Oil Shale Reserves

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By FLORENCE RUCKER COLLINS

With Micropaleontologic Study of the Topagoruk Test Wells, Northern Alaska

By HARLAN R. BERGQUIST

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TEST WELLS, TOPAGORUK AREA, ALASKA

By Florence Rucker Collins

ABSTRACT

Topagoruk test well 1 and East Topagoruk test well 1 were drilled on the northern coastal plain of Alaska in 1950 and 1951, as part of the United States Navy program for petroleum exploration in Naval Petroleum Reserve No. 4.

Topagoruk test well 1 was drilled to a depth of 10,503 feet and tested rocks ranging in age from Cretaceous to Devonian. The test well is on a small deeply buried anticline discovered by seismograph survey. The section penetrated consists of shale, siltstone, and sandstone, with several beds of chert conglomerate in the Devonian sequence; the absence of limestone and permeable clastic rocks in beds of Paleozoic age and the lack of all but a minor show of oil resulted in abandoning the test.

East Topagoruk test well 1 was located on an anticline in rocks of the Nanushuk group (Lower and Upper Cretaceous) defined by reflection seismograph. Beneath a thin mantle of the Gubik formation (Pleistocene), the drilling penetrated about 3,500 feet of rock of the Nanushuk group, the upper part of which is dominantly sandstone; the lower part of the sequence is mostly shale. The test was abandoned at a total depth of 3,589 feet; no shows of oil and no commercial shows of gas were found.

INTRODUCTION

Topagoruk test well 1 and East Topagoruk test well 1 were drilled in 1950 and 1951 as part of the petroleum exploration program of the United States Navy in Naval Petroleum Reserve No. 4, northern Alaska. The test wells are approximately 80 miles south-southeast of Point Barrow (see fig. 14) in a region of numerous lakes and marshy tundra (see fig. 15).

A network of meandering streams drain into the Topagoruk and Chipp Rivers and Admiralty Bay.

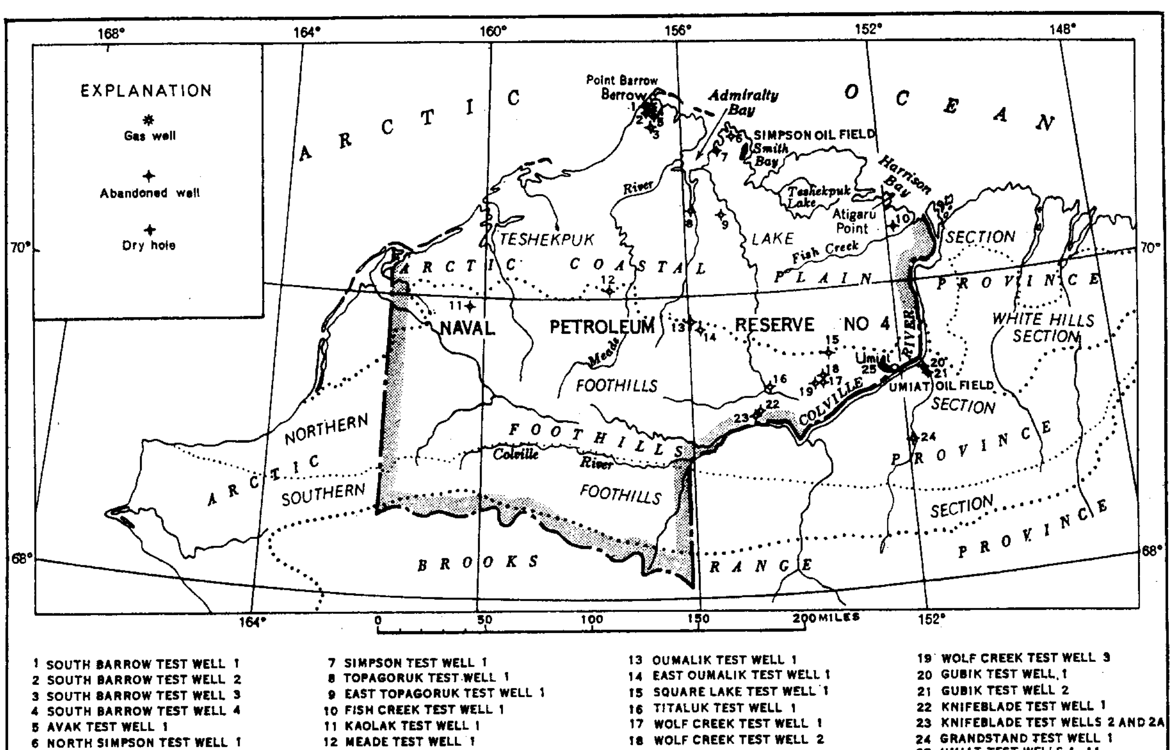

Figure 14.—Index map of northern Alaska showing location of test wells and oil fields.

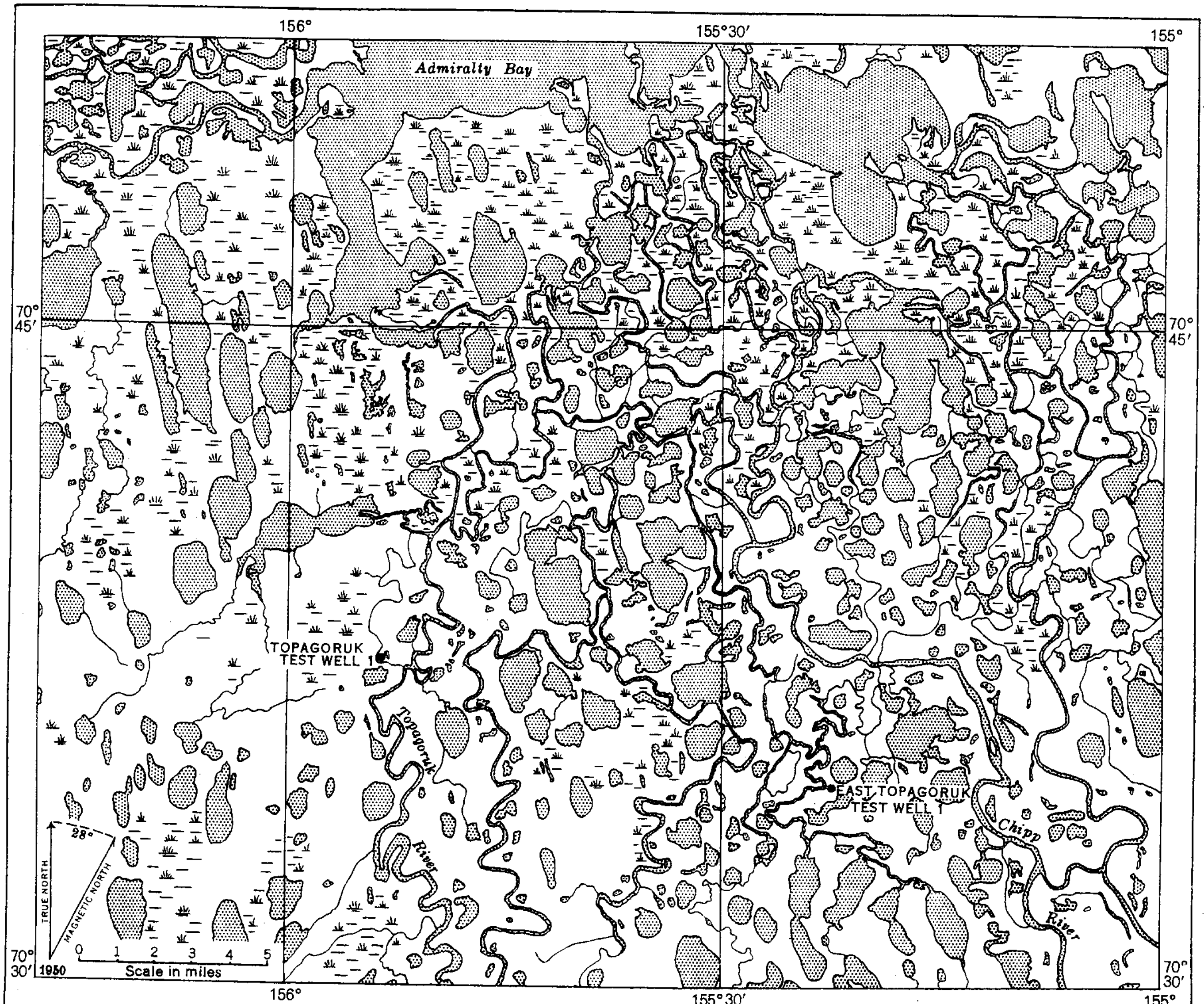

FIGURE 15.—Map showing location of Topagoruk test well 1 and East Topagoruk test well 1.

The ground is permanently frozen beneath the tundra to a depth of several hundred feet. Polygonal ground, typical of many areas of permafrost, forms much of the surface. No pre-Pleistocene outcrops are present in the area, and both tests were drilled on small anticlines defined by reflection seismograph work done in 1950 by the United Geophysical Co., Inc. (See fig. 16.) Earlier geophysical studies included magnetometer surveys by the U. S. Navy and the U. S. Geological Survey in 1945–46 and airborne reconnaissance gravity surveys by United Geophysical Co., Inc., in 1947. The gravity data show that the holes are on a contour "terrace" between an observed gravity high 30 miles to the east and a low 50 miles to the southwest. These features are elongate and trend north. The airborne magnetometer shows the Topagoruk area to have a steep gradient from a low-intensity area 10 miles west of the test wells to an area of high intensity centered in Smith Bay to the northeast.

This report presents detailed geologic and engineering data obtained in drilling the two holes; much of the information is summarized on plates 17 and 18. Technical data have been recorded by Arctic Contractors, who, under contract with the Navy, drilled test wells in many localities throughout the Reserve. The United States Geological Survey, as a cooperating agency, studied the geology of the area both in the field and in the laboratory; geophysical studies and electric logs were made by the United Geophysical Co., Inc., and the Schlumberger Well Surveying Corp., respectively. The help of many engineers, geophysicists, and geologists connected with the above organizations is gratefully

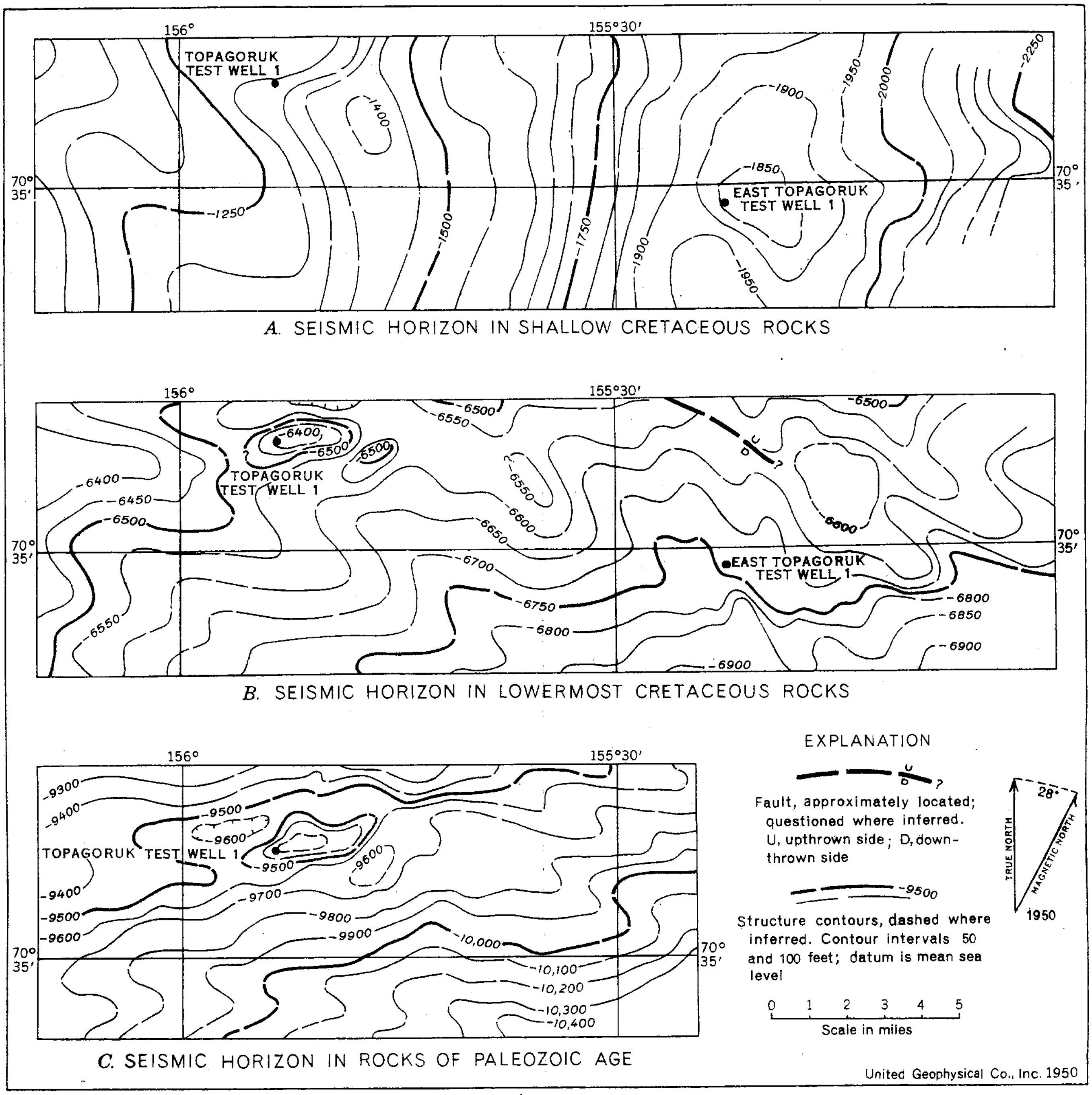

FIGURE 16.—Structure-contour maps of the Topagoruk area.

acknowledged. Microfossils were identified by Harlan R. Bergquist, and the stratigraphic distribution of fossils in the test wells of northern Alaska will be presented by him in another chapter of this series. Mollusks were identified by Ralph W. Imlay, and plants, by James M. Schopf. Fish remains were studied by D. H. Dunkle, of the United States National Museum. The heavy-mineral data in this report is part of a regional study of the heavy-mineral zones by Robert H. Morris.

TOPAGORUK TEST WELL 1

Location: Lat 70°37′30″ N., long 155°53′36″ W.
Elevation above sea level: Ground, 28 feet; kelly bushing, 42 feet.
Spudded: June 15, 1950.
Completed: September 28, 1951, dry and abandoned.
Total depth: 10,503 feet.

Topagoruk test well 1 is the second deepest test well drilled in Naval Petroleum Reserve No. 4; only Oumalik test well 1, about 50 miles south, is deeper (Robinson, 1956). The drilling penetrated rocks ranging in age from Quaternary to Devonian. It is on a small buried anticline having about 150 feet of closure on Permian rocks at a depth of 9,500 feet and about 100 feet of closure on beds near the base of the Cretaceous strata. (See fig. 16.) The anticline, which was defined in 1950 by reflection seismograph, is not present in the shallower Cretaceous rocks (fig. 16). Regional studies (Payne and others, 1951) and seismic surveys indicate a rapid thickening of rocks of Paleozoic and Mesozoic age as the beds dip southward from the structurally high area near Point Barrow. Greater knowledge of the stratigraphy, including the presence and location of unconformities and suitable reservoir conditions, was necessary to evaluate the petroleum possibilities of the northern part of the Reserve. In the Topagoruk area the rocks of Paleozoic age were thought to be present within reach of the drill. The Lisburne group, a thick sequence of Mississippian rocks exposed in the Brooks Range to the south, was the deepest objective of this test. In the area of outcrop these beds include porous limestones and dolomites, some of which have a strong petroliferous (?) odor (Bowsher and Dutro, 1957.) In Topagoruk test well 1, however, these rocks are absent, and beds of shale and conglomerate of Devonian age are unconformably overlain by red beds of unknown age which in turn are overlain by impermeable siliceous sandstone of Permian age. The beds of Mesozoic age, as well as the older rocks, did not contain oil or gas in commercial quantities; the rare sandstone beds in the Jurassic and Triassic sequence did not have any shows of oil or gas, and although some beds of the Cretaceous have good reservoir properties and one sandstone below 5,960 feet possibly contains a small amount of gas, the electric log shows them to be water bearing.

STRATIGRAPHY

Stratigraphic units in Topagoruk test well 1 are as follows:

	Depth (feet)
Pleistocene:	
Gubik formation	14–50
Cretaceous:	
Grandstand formation	50–1,350
Topagoruk formation	1,350–3,900
Oumalik formation	3,900–6,600
Jurassic:	
Upper Jurassic rocks	6,600–7,820
Middle Jurassic rocks	7,820–8,640
Triassic:	
Shublik formation	8,640–9,380
Permian rocks	9,380–9,770
Red beds (age undetermined)	9,770–10,040
Middle (Lower?) Devonian rocks	10,040–10,503

GUBIK FORMATION

Approximately 40 feet of unconsolidated sand of the marine Gubik formation (Pleistocene) overlies indurated Cretaceous rocks in this test well. The very fine to medium sand is composed of well-rounded to subrounded, clear, white, and yellow quartz grains with some yellow and black chert pebbles. In many places, including East Topagoruk test well 1, the Gubik formation contains marine microfossils. None were found in this well, however, and the sand is correlated with the Gubik formation on the basis of lithology. The contact between this and the underlying Grandstand formation is placed at 50 feet. One sample representing the sediments from 14 to 57 feet was made up primarily of Gubik material, with a little sand and coal from the Cretaceous rocks below, and the contact is arbitrarily placed near the bottom of the interval.

GRANDSTAND FORMATION

The Grandstand formation is distinguished from the overlying Gubik formation by color, greater angularity, greater consolidation of the sand, presence of coal and clay ironstone, and its distinctive microfauna. (See p. 311.) The only representative of the Nanushuk group (Gryc and others, 1956) in the Topagoruk area, the Grandstand formation, is Early Cretaceous in age.

This formation is composed primarily of marine sandstone, but it also contains a large amount of marine clay shale and a few thin beds of coal. The sandstone beds range from a few feet to 50 feet in thickness and are commonly separated from other sandstone beds by only 1 or 2 feet of clay shale. The typical sandstone is light gray, has a salt-and-pepper appearance, and is calcareous in part. Effective porosity (Tickell, 1939, p. 26) ranges from 11 to 27 percent, and air permeability, from impermeable to 316 millidarcys. (See table on p. 289.) The sandstone is medium to fine grained, usually well sorted, and composed of subangular to subrounded grains of white and clear quartz and some gray chert and dark rock fragments. The grains have low sphericity and are commonly frosted. Mica, carbonaceous material, and pyrite are rare. Clay shale in beds 1–40 feet thick is more common in the upper part of the formation than near the base. The clay shale is medium gray, silty in part, nonmicaceous, and noncalcareous and commonly contains laminae of siltstone or sandstone. Thin coal beds, concentrated between 300 and 550 feet and from 850 to 1,050 feet, make up a minor part of the formation and indicate minor regressions of the sea in which the rest of the formation was deposited. Clay ironstone nodules are scattered through the beds above 1,200 feet and are especially common between 550 and 1,000 feet.

The Grandstand formation and the underlying Topagoruk formation contain microfossils typical of the *Verneuilinoides borealis* faunal zone (see page 311); the Topagoruk formation, however, is dominantly siltstone and clay shale, whereas the Grandstand formation is dominantly sandstone. The contact is arbitrarily placed at 1,350 feet—below the base of the sandy sequence—although deposition was continuous and the change from shale to sandstone is gradual.

TOPAGORUK FORMATION

The type section of the marine Topagoruk formation (Lower Cretaceous) has been established (Gryc and others, 1956) as the beds penetrated in drilling Topagoruk test well 1 between 1,350 and 3,900 feet. The formation is composed of medium- to medium-dark-gray and clay shale a few thin beds and laminae of medium-gray siltstone; it also contains beds of sandstone most of which are less than 10 feet thick.

The clay shale is micaceous, silty, and noncalcareous; it contains a few scattered carbonaceous partings and carbonized plant particles. Most of it has poor to fair shaly cleavage. The medium-gray siltstone is present in thin beds, laminae, and small lenses in the shale and decreases gradually with depth from about 25 percent of the rock to less than 10 percent. It is very argillaceous, slightly calcareous in part, and micaceous; some is crossbedded at a low angle. The sandstone is very fine grained, except for some minor fine-grained beds, and is concentrated in the upper 800 feet in 1- to 20-foot beds and in one bed about 60 feet thick. Rare sandstone beds, a few inches to 10 feet thick, are present to a depth of 3,300 feet. The sandstone is medium light gray, silty, and argillaceous; a few beds are slightly to very calcareous, and most are slightly micaceous. The sand grains are subangular to subrounded, and the composition is similar to that of the sandstones of the overlying Grandstand formation. Some of the clay, silt, and sand were deposited in irregular streaks and lenses. Bands of silt or sand intermingled with clay impart a marbled appearance and probably reflect contemporaneous deformation caused by slumping of unconsolidated sediments.

The *Verneuilinoides borealis* foraminiferal assemblage is present in much of the formation (see p. 311), and at 3,249 feet a specimen of *Cleoniceras* (n. subgen.) n. sp., an ammonite of Albian age, was recovered.

At 3,900 feet the Topagoruk formation in this well lies on the underlying Oumalik formation with a slight angular unconformity. The shale above 3,900 feet is horizontal or very gently dipping, whereas the shale of the Oumalik formation below that depth dips as much as 8°. This unconformity can be traced elsewhere in the Reserve by means of seismic records. Lithologically, the two formations are similar, but the shale of the Topagoruk is generally slightly softer and lighter in color and tends to break into more equidimensional, less angular fragments than the older shale. The underlying Oumalik formation also contains a different microfaunal assemblage.

OUMALIK FORMATION

The marine Oumalik formation (Lower Cretaceous) is composed almost entirely of medium-dark to dark-gray clay shale and claystone. The rock is slightly silty and micaceous in part and may contain carbonaceous particles and a few laminae of argillaceous siltstone. The sandstone in the lower part of the formation (between 5,000 and 6,600 feet) is slightly darker than that in the overlying formations and is composed of angular to subangular very fine grains of clear quartz, with rare white quartz and dark rock fragments. Some of the sandstone has a brownish tinge, the result of a yellowish-brown stain on the quartz grains. The sandstone beds are commonly less than 10 feet thick and have no shows of oil; but one thicker bed, at 5,960–5,987 feet, was slightly oil stained. It was impermeable, however, and a formation test recovered no oil or gas.

UPPER JURASSIC ROCKS

Between core 55 at 6,510 feet and core 56 at 6,743 feet both lithology and fauna change. The exact depth at which they change is difficult to determine, owing to contamination of the ditch samples by caving shale, but it is probably close to 6,600 feet. Below it, Upper Jurassic rock consisting of dark marine clay shale is present to a depth of 7,820 feet. It is easily distinguished from the overlying Oumalik formation by its grayish-black color, absence of siltstone and sandstone laminae, abundant pyrite, and especially, the quartz and chert grains. These grains are fine sand to granule sized, are very well rounded, pitted or polished clear quartz, and are scattered singly or in small pockets through the shale. Smooth, very well-rounded gray and black chert grains of medium sand to granule size are also randomly distributed through the rock, although they are rare. The black shale matrix contains almost no silt and the rare particles of mica are very minute. Grains of bluish-green glauconite are rare to common. At the base of the unit is a glauconite sandstone composed of about 75 percent of grayish-green glauconite in a black clay matrix that

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also contains a small amount of very fine-grained subangular quartz. Sandstone higher in this sequence, at 6,800 feet, is represented only by rare chips of medium- to fine-grained glauconitic and pyritic sandstone of well-rounded clear quartz grains. A distinctive and prolific microfauna, as well as a mollusk from 7,060 feet, establishes the age of the beds as Late Jurassic. (See p. 281.)

MIDDLE JURASSIC ROCKS

Beneath the Upper Jurassic rocks is 100 feet or more of medium-gray siltstone which is argillaceous, noncalcareous, and very slightly micaceous and has abundant irregular discontinuous patches of medium-dark-gray clay shale. It is underlain by clay shale beds that are dark gray and micaceous and that contain abundant minute pyrite streaks and lines an inch or less long. These beds constitute an 820-foot sequence of Middle Jurassic rocks, between 7,820 and 8,640 feet, in Topagoruk test well 1. A core at 8,103–8,113 feet contained ammonites (*Pseudolioceras?* sp. and *Tmetoceras* sp., identified by Ralph W. Imlay) which are typical of the lower part of the Middle Jurassic (Lower Bajocian). The ammonites normally are near the base of the Middle Jurassic, and some of the rock below 8,113 feet may be of Early Jurassic age. No Early Jurassic fossils were found, however; and as the rock below the ammonites is similar to that above them, the whole sequence is here designated as Middle Jurassic.

SHUBLIK FORMATION

Ostracodes, echinoid spines, and pyritic pelecypods present in ditch samples from 8,640 feet downward indicate that the top of the Shublik formation of Late Triassic age is close to 8,640 feet. Upper Triassic pelecypods *Halobia* sp. and *Monotis* sp. and Triassic Foraminifera (see p. 313) were also recovered from this formation. These beds are poorly represented by the ditch samples, which are badly contaminated with cavings. Two cores are composed of dark-gray slightly pyritic clay shale having a few laminae of medium-light-gray very calcareous siltstone, and both the ditch samples and the electric log indicate that most of the formation is the same type of rock. The only other rock types noted in the samples were a few thin beds of siliceous sandstone at 8,720–8,790 feet, a thin bed of very fine-grained glauconitic sandstone at 8,820 feet, dark-brownish-gray limestone at 9,160 feet, and rare dark-gray calcareous siltstone below 8,960 feet. Below 9,100 feet the electric log shows some "kicks" in the resistivity curve and a gradual increase in the spontaneous-potential curve that were not reflected in the samples.

PERMIAN ROCKS

Permian strata in this test well, first found at approximately 9,380 feet, are composed of light-gray sandstone and siltstone; underlying rocks, also considered to be Permian, include conglomerate and mottled claystone of red and gray, as well as sandstone and siltstone similar to that above the conglomerate.

The uppermost 140 feet consists of light-gray siliceous sandstone that is dolomitic in the upper part and interbedded with siliceous siltstone near the base. The sandstone is very fine grained and composed primarily of subangular white and clear quartz of moderate sphericity, commonly frosted; some grains, however, are clear angular quartz and have low sphericity. Some of the sand grains have been enlarged by silica deposited in optical continuity, while others have been roughened by solution. Dark rock fragments and minute carbonaceous particles are rare, and mica is absent. Irregular laminae of medium-dark-gray siliceous clay shale are present, although uncommon. Brachiopods (*Lingula* sp.) are present, and coelocanth fish teeth from 9,438 feet (see p. 283) establish the age of the beds. The lower 13 feet of the rock contains several beds of siliceous claystone that are a few inches to nearly 4 feet thick. Some of the claystone and some of the siltstone interbedded with it are a mottled medium gray and grayish red. In some places the red parts fade gradually into the gray; elsewhere the color boundaries are sharp, although they do not coincide with changes in texture or grain size in the rock.

Beneath the mottled claystone is conglomerate composed predominantly of white chert pebbles, with a few pebbles of gray and black chert, in a matrix of clear and white quartz sand and siliceous cement. The pebbles are ¼–¾ inch in diameter and are subround to well rounded. The conglomerate is underlain by a 50-foot bed of light-gray very fine- to fine-grained very siliceous massive sandstone, and that in turn is underlain by medium-dark-gray clay shale and siliceous siltstone. The base of the sequence, at 9,770 feet, is marked by the abrupt appearance of red beds.

RED BEDS

Beds of brick-red to grayish-red claystone, siltstone, and sandstone, with a few thin beds of red chert conglomerate and rare interlaminated red and green shale, are interbedded from 9,770 to 10,040 feet. No fossils were found in these rocks, and their age is unknown. They are beneath rocks of Permian age, and are separated by an angular unconformity from Devonian strata. The red beds are similar lithologically to red beds in the Siksikpuk formation (Permian?) that crop out in the Brooks Range to the south (Patton, 1957), but the evidence is too scanty and the distance too great to warrant correlating the two sequences.

MIDDLE (OR LOWER?) DEVONIAN ROCKS

An angular unconformity separates the Devonian rocks from the overlying red beds: cores show that beds of Devonian age dip 35°–60°, whereas the younger strata dip 8° or less. The Devonian strata are composed of approximately equal amounts of interbedded medium-gray chert conglomerate and dark-gray carbonaceous shale and claystone. The conglomerate is very siliceous and sandy, and contains subangular white, gray, and black chert pebbles ⅛–¼ inch in diameter in the upper part, increasing to a maximum of 2½ inches near the bottom of the hole. The matrix is coarse to fine chert sand, with some silty and argillaceous material, well cemented by additional silica. The pebbles are either scattered or in beds. Shaly streaks, carbonaceous films or partings, and minute cubes and irregular patches of pyrite are present. The clay shale is grayish black and slightly silty and siliceous, with discontinuous carbonaceous partings, some of which are covered with carbonized fragments of plants identified by James M. Schopf as Middle (Early?) Devonian in age. Pyrite nodules are rare. The rocks are indurated by siliceous cement, but show no sign of metamorphism.

The bottom of the hole, at 10,503 feet, is in chert conglomerate.

DESCRIPTION OF CORES AND CUTTINGS

The description of the rocks penetrated in Topagoruk test well 1 and in East Topagoruk test well 1 is based on an examination of cores and ditch samples. Some ditch samples were composed of sandstone through depths which are represented on the electric log by curves typical of clay shale; in Topagoruk test well 1, ditch samples below 4,200 feet were contaminated by caving of rock higher up in the hole. The graphic logs (pls. 17 and 18) generally show the lithology inferred from the electric logs, as that is believed to be more accurate. The material was described dry, and colors were determined by comparison with the Rock Color Chart (Goddard, 1948). All depths are measured from the top of the kelly bushing.

Clay ironstone is a yellowish-gray to grayish-yellow and grayish-orange dense hard argillaceous rock with conchoidal fracture; it is sideritic and usually reacts with cold dilute hydrochloric acid.

Abundance of microfossil specimens mentioned at the beginning of each core sampled is defined as follows: 1–4 very rare; 5–11 rare; 12–25 common; 26–50 abundant; over 50, very abundant.

Lithologic description

[Where no cores are listed, description is based on cutting samples]

Core	Depth (feet)	Description
----	0–14	Kelly bushing to ground level.
----	14–57	Sand, very fine- to medium-grained, with a few coarse grains; composed of very well-rounded to subrounded (rarely subangular) clear, white, and yellow quartz, with some yellow and black chert. Very rare coal (?) particles also present. The top of the Grandstand formation placed at 50 ft.
----	57–120	No samples received. Arctic Contractors' well geologist John Bollenbacher lists "clay shale with coal interbeds and interbeds of limestone and calcareous silts."
----	120–130	Coal, with some greenish-gray very fine-grained very silty very calcareous sandstone, of subangular clear and white quartz and rare chert grains. Samples from 120 to 200 ft contain a large amount of cement and chert-pebble contamination from the surface.
----	130–140	No sample. Well geologist reports "shale, medium-hard, gray, with fine sand interbeds and few thin coal seams" between 111 and 302 ft.
----	140–170	Sandstone, light-olive-gray, very fine- to fine-grained, very calcareous, hard, of angular to subangular white and clear quartz and a few dark grains. Pyrite and coal rare.
----	170–180	Coal with some sandstone as above.
----	180–190	Sandstone as above, with some coal.
----	190–200	Coal, with small amount of calcareous sandstone, grading to sandy limestone.
----	200–240	Sandstone, very fine-grained; composed of subangular white quartz. Rare fragments of hard black shale at 220–230 ft. Well geologist reports clay shale.
----	240–260	Sandstone as above, and very sandy limestone, grading to very calcareous sandstone with a few fragments of black soft carbonaceous shale.
----	260–300	Sandstone, light-gray, very fine-grained; composed of subangular white quartz with rare dark rock fragments.
----	300–302	No sample.
1	302–312	Recovered 10 ft: Microfossils absent. 5 ft, sandstone, light-gray, fine-grained, salt-and-pepper, slightly calcareous, massive, moderately well-indurated. Thin streaks of carbonaceous material in lower 6 in. Friable near base. At 304 ft effective porosity and air permeability parallel to the bedding 11.0 percent and 5.17 millidarcys; perpendicular to the bedding they are 11.1 percent and impermeable, respectively. Carbonate content at 304 ft 16.38 percent by weight.

Lithologic description—Continued

Core	Depth (feet)	Description
		1 ft 8 in., interbedded medium-light-gray clay shale and light-gray siltstone. 3 ft 4 in., sandstone, light-gray, fine-grained, very friable, with some thin streaks of carbonaceous material. Thin bed of coal at top of sandstone. Beds approximately flat lying.
----	312–330	Sandstone as at top of core 1 with some coal in the lower part and a small amount of black shale.
----	330–340	Sandstone, light-gray, very fine-grained.
----	340–350	Coal, with small amount of light-yellowish-gray sandstone and greenish-gray very fine- to fine-grained sandstone.
----	350–360	Sandstone, light-yellowish-gray and light-greenish-gray, very fine- to fine-grained, with some coal and black shale containing laminae of coal.
----	360–380	Coal and light-greenish-gray sandstone, with small amount of black clay shale and rare pyrite.
----	380–390	Sandstone and rare coal; some clay shale suggested by electric log.
----	390–410	Coal, with some sandstone and black clay shale.
----	410–420	No sample.
----	420–440	Sandstone and coal, with rare slightly calcareous clay ironstone and pyrite; clay shale suggested by electric log.
----	440–460	Sandstone with a small amount of coal.
----	460–470	Sandstone (the electric log suggests much clay shale) and rare coal and siltstone; latter very sandy, argillaceous, and calcareous.
----	470–480	No sample.
----	480–510	Clay shale and sandstone (clay shale in lower part), with small amount of very sandy calcareous argillaceous siltstone. Some coal and black clay shale in bottom 10 ft.
----	510–520	Sandstone as above, and clay shale, but with more siltstone and some clay ironstone and black shale.
----	520–530	Clay shale, medium-gray, silty, noncalcareous, nonmicaceous, hard, with some sandstone, clay ironstone, and siltstone; pyrite common.
----	530–540	Sandstone and clay shale, with small amount of coal and ironstone; pyrite, black clay shale, and siltstone rare.
----	540–550	Sandstone and siltstone with some coal; small amount of clay shale and ironstone.
----	550–560	Coal, with little medium-gray clay shale and clay ironstone.
----	560–590	Siltstone, coal, sandstone, gray and black clay shale, and ironstone.
----	590–596	No sample.

Lithologic description—Continued

Core	Depth (feet)	Description
2	596–608	Recovered 10 ft: Microfossils absent. Sandstone, light-gray, fine- to medium-grained, salt-and-pepper, friable, with some streaks of carbonaceous material, plant fragments in mudstone streaks, and abundant fragments of *Inoceramus* shells. At 603 ft effective porosity 27.2 percent, and air permeability 316.2 millidarcys, parallel to bedding; perpendicular to bedding, 26.2 percent and 219.8 millidarcys, respectively.
----	608–610	No sample.
----	610–640	Sandstone, greenish-gray, very fine- to fine-grained, slightly calcareous; composed of subangular white and clear quartz grains; clay ironstone rare; siltstone rare at base.
----	640–670	Sandstone as above, medium-gray clay shale, and small amount of coal, siltstone, and clay ironstone.
----	670–690	Sandstone, with small amount of medium-gray clay shale and clay ironstone throughout and small amount black shale in upper 10 ft.
----	690–720	Clay shale, medium-gray, silty, noncalcareous, with some sandstone and rare clay ironstone.
----	720–740	Sandstone, medium-light-gray, very fine-grained, silty, slightly calcareous, with small amount of clay shale in lower part.
----	740–760	Limestone, medium-dark-gray, very silty and argillaceous, with small amount of sandstone.
----	760–780	Sandstone, as above, with small amount of limestone, clay shale, and clay ironstone.
----	780–790	Sandstone, gray and black shale, and coal.
----	790–820	Clay shale, gray and black, with some sandstone.
----	820–840	Sandstone, medium-light-gray, fine- to medium-grained, salt-and-pepper, silty, very slightly argillaceous, very slightly calcareous, friable; composed of subround to subangular clear and white quartz with small amount of gray and black rock fragments. Some gray shale, and a little clay ironstone also present.
----	840–860	Sandstone as above, with coal.
----	860–870	Sandstone as above, with a little clay ironstone and black clay shale in the lower part.
----	870–880	Coal, black and gray clay shale, rare limestone fragments.
----	880–890	Coal, some limestone, and clay shale.
----	890–900	Coal with a little sandstone and rare clay ironstone and black shale.

Lithologic description—Continued

Core	Depth (feet)	Description
----	900–910	Coal and salt-and-pepper sandstone.
----	910–911	No sample.
3	911–919	Recovered 8 ft: Microfossils very abundant. Claystone, light-gray, with hackly to subconchoidal fracture. Feels slippery. Marcasite nodule 1 in. across at bottom of core. Small pelecypod shell fragments present, including *Arctica?* sp., and *Thracia stelcki* McLearn, and *Corbula*, identified by Ralph W. Imlay.
----	919–920	No sample.
----	920–930	Clay shale, gray and black, with some coal and clay ironstone.
----	930–940	Clay shale, medium-gray, with rare sandstone, siltstone, and ironstone.
----	940–950	Clay shale, medium-gray, with a little clay ironstone and coal.
----	950–970	Coal, black, shiny, with blocky fracture, and small amount of clay ironstone, and black and medium-gray clay shale.
----	970–990	Coal and gray clay shale, with some clay ironstone and salt-and-pepper sandstone.
----	990–1, 010	Coal, gray clay shale, and sandstone.
----	1, 010–1, 030	Coal, with small amount of gray clay shale.
----	1, 030–1, 040	Clay shale, medium-gray, with some coal and sandstone.
----	1, 040–1, 060	No sample.
----	1, 060–1, 070	Coal, sandstone, and clay shale.
----	1, 070–1, 100	Sandstone, light-olive-gray, very fine-grained, very silty and argillaceous, very calcareous, with some gray clay shale and a little coal.
----	1, 100–1, 170	Sandstone as above with some clay shale and clay ironstone at 1,110–1,125 ft and 1,145–1,150 ft.
----	1, 170–1, 190	Sandstone as above, with siltstone and clay shale; sample composed mostly of Fibertex.
----	1, 190–1, 200	Sandstone, as above, with gray clay shale and clay ironstone.
4	1, 200–1, 209	Recovered 9 ft: Microfossils absent. Sandstone, light-gray, fine- to medium-grained, salt-and-pepper, very slightly calcareous, moderately friable, with trace of mica; grains subangular.

Depth (feet)	Effective porosity (percent)	Air permeability (millidarcys)	Content of carbonate minerals (percent by weight)
1, 204P [1]	26.0	200.4	14.7
1, 204N [2]	23.1	128.9	----------
1, 209P	21.3	169.1	13.2
1, 209N	16.6	108.8	----------

[1] P, parallel to bedding. [2] N, normal to bedding.

Lithologic description—Continued

Core	Depth (feet)	Description
----	1, 209–1, 210	No sample.
----	1, 210–1, 290	Sandstone, light-olive-gray, very fine-grained, very silty and argillaceous, calcareous; and medium-light-gray medium- to fine-grained salt-and-pepper slightly calcareous sandstone; grades to very sandy and argillaceous medium-gray siltstone, which is slightly calcareous and slightly micaceous toward base.
----	1, 290–1, 320	Siltstone as above, with some very fine-grained sandstone.
----	1, 320–1, 340	Sandstone (in the upper part), siltstone, and clay shale.
----	1, 340–1, 370	Siltstone and clay shale, with small amount of sandstone. Top of the Topagoruk formation at 1,350 feet.
----	1, 370–1, 380	Clay shale, with small amount of siltstone and very fine-grained sandstone and salt-and-pepper sandstone; pyrite common.
----	1, 380–1, 450	Clay shale, medium-dark-gray, noncalcareous, with small amount of siltstone and rare streaks of sandstone; some pyrite.
----	1, 450–1, 490	Siltstone, light-olive- to olive-gray, slightly micaceous, slightly calcareous; streaks of sandstone at 1,480–1,490 ft (shale indicated by electric log).
5	1, 490–1, 501	Recovered 11 ft: Microfossils very abundant. Clay shale, medium-gray, with hackly cleavage, rare silty partings, abundant plant fragments; beds flat lying. *Inoceramus* sp. and *Pleuromya* sp. shell fragments present.
----	1, 501–1, 590	Siltstone and clay shale as above; pyrite common.
----	1, 590–1, 610	Sandstone and siltstone, with some clay shale; pyrite rare.
----	1, 610–1, 640	Clay shale and siltstone, with rare streaks of sandstone.
----	1, 640–1, 720	Clay shale, with small amount siltstone.
----	1, 720–1, 740	Siltstone, sandstone, and clay shale.
----	1, 740–1, 770	Clay shale and siltstone with streaks of sandstone.
----	1, 770–1, 790	Sandstone, light-yellowish-gray, very fine-grained, very silty, noncalcareous, with many tan, black, and yellow subangular and subrounded grains. Streaks of clay shale and siltstone in bottom 15 ft.
6	1, 790–1, 800	Recovered 5 ft: Microfossils common. 1 ft 6 in., sandstone, medium-light-gray, very fine-grained, silty, argillaceous, slightly micaceous, noncalcareous. Sand grains subangular, largely clear quartz with some white and dark-gray grains. Effective porosity 18.1 percent; air permeability 11.8 millidarcys.

Lithologic description—Continued

Core	Depth (feet)	Description
		1 ft 2 in., claystone, medium-gray, silty, micaceous, very slightly calcareous.
		2 ft 4 in., sandstone, medium-light-gray, very fine- to fine-grained, silty, argillaceous, micaceous, slightly calcareous (dolomitic?), with evenly bedded laminae marked by scattered flakes of carbonized plant remains on partings. Dip 5°. Impermeable to air; effective porosity 17.7 percent.
----	1, 800–1, 810	Clay shale and sandstone, light-yellowish-gray, very fine-grained.
----	1, 810–1, 860	Clay shale and siltstone with streaks of medium-gray sandstone.
----	1, 860–1, 910	Sandstone, medium-gray, clay shale and siltstone.
----	1, 910–1, 935	Clay shale, medium-dark-gray, noncalcareous, with small amount of siltstone and sandstone. Pyrite rare.
----	1, 935–1, 960	Sandstone, with small amount of siltstone and clay shale.
----	1, 960–2, 040	Clay shale, medium- to medium-dark-gray, noncalcareous; and medium-gray slightly calcareous siltstone.
----	2, 040–2, 087	Sandstone, medium-gray, very fine-grained, silty, slightly calcareous, with rare carbonaceous partings and small amount sandy limestone in bottom 10 ft.
7	2, 087–2, 097	Recovered 10 ft: Microfossils rare.
		5 ft, sandstone, medium-gray, very fine-grained, very silty, very calcareous; grades to very calcareous sandy siltstone at base; 2½ ft below top of core is 4-in. layer of medium-dark-gray to light-olive-gray slightly to very calcareous claystone, with small slickensides (dipping approximately 45°); lower part broken into angular to subround fragments, in matrix of sandstone. Minute vertical calcite veinlets occur at base of section.
		1 ft 10 in., clay shale, medium-dark-gray, slightly micaceous, slightly carbonaceous, with scattered laminae and lenses of medium-gray siltstone. Beds dip less than 3°.
		3 ft 2 in., sandstone as in lower part of core; 2 thin 1-in. layers of clay shale. *Ditrupa* sp. present.
----	2, 097–2, 100	No sample.

Lithologic description—Continued

Core	Depth (feet)	Description
----	2, 100–2, 200	Clay shale, medium-dark-gray, slightly micaceous, slightly carbonaceous, with some sandstone and siltstone.
----	2, 200–2, 350	Clay shale, medium-dark-gray, noncalcareous, very slightly micaceous in part, with some medium-gray siltstone, slightly calcareous in part.
----	2, 350–2, 370	Sandstone, medium-light-gray, very fine-grained, with small amount of siltstone and clay shale.
----	2, 370–2, 390	Clay shale and siltstone, grains of coal.
8	2, 390–2, 399	Recovered 9 ft: Microfossils very abundant.
		Clay shale, medium- to medium-dark-gray, noncalcareous; commonly has hackly cleavage; some laminae and thin lenses of silty medium-gray shale. Small patches of sandy carbonaceous silt and carbonized plant fragments throughout. Beds approximately flat lying.
----	2, 399–2, 400	No sample.
----	2, 400–2, 560	Clay shale and siltstone. Siltstone has grains of coal. Siltstone decreases in abundance from almost half the samples at 2,400 ft to absent at 2,530 ft; small amount, partly occurring as laminae in the shale, present from 2,530 ft to 2,560 ft.
----	2, 560–2, 565	Sandstone, very fine-grained, with siltstone and clay shale.
----	2, 565–2, 580	Clay shale, as above.
----	2, 580–2, 620	Sandstone, medium-gray, medium-fine-grained, salt-and-pepper, friable, very calcareous; grades to very fine grained; silty in bottom 10 ft.
----	2, 620–2, 637	Clay shale, with small amount of siltstone.
9	2, 637–2, 642	Recovered 3 ft: Microfossils common.
		1 ft 6 in., siltstone, medium-dark-gray, very argillaceous, slightly micaceous, noncalcareous; grades into unit below.
		1 ft 6 in., clay shale, medium-dark-gray, noncalcareous, with some slightly silty streaks.
----	2, 642–2, 650	No sample.
----	2, 650–2, 680	Clay shale, with sandstone at 2,655–2,660 ft and small amount of siltstone with carbonaceous partings.
----	2, 680–2, 740	Clay shale, with some siltstone at base.
----	2, 740–2, 750	Sandstone, with clay shale and siltstone.
----	2, 750–2, 830	Clay shale, with streaks of siltstone.
----	2, 830–2, 900	Clay shale as above, with interbedded sandstone and siltstone.
----	2, 900–2, 940	Clay shale, with rare laminae of medium-light-gray siltstone.

Lithologic description—Continued

Core	Depth (feet)	Description
10	2, 940–2, 950	Recovered 9 ft: Microfossils abundant. Clay shale, medium-dark-gray, noncalcareous, very slightly micaceous, with thin (as much as 1½ in.) beds, lenses, and laminae of medium-light-gray argillaceous noncalcareous poorly cross-bedded siltstone, containing rare fine carbonaceous partings. Siltstone makes up approximately 15 percent of the total recovered core.
----	2, 950–2, 970	Clay shale with rare laminae of siltstone.
----	2, 970–3, 010	Clay shale and siltstone.
----	3, 010–3, 030	Clay shale, with rare siltstone laminae.
----	3, 030–3, 050	Clay shale and salt-and-pepper sandstone.
----	3, 050–3, 220	Clay shale with scattered laminae and thin beds of siltstone.
----	3, 220–3, 240	Clay shale, with thin beds of medium-light-gray very fine-grained sandstone, carbonaceous laminae, and rare siltstone.
11	3, 240–3, 249	Recovered 6 ft: Microfossils rare. 1 ft, claystone, medium-gray, very silty, micaceous, slightly calcareous, with flakes of carbonaceous material scattered throughout. 2 ft 5 in., claystone, very silty, micaceous, noncalcareous, with abundant flakes of carbonized plants scattered throughout. 5 in., siltstone, medium-light-gray, very sandy, slightly calcareous, with carbonaceous partings and thin beds (as much as one-half inch) of medium-gray clay shale. 2 ft 2 in., clay shale as in core above, but with increasing amount of mica and flakes of carbonized plant remains toward base of core. A 1-in. layer of medium-gray very argillaceous noncalcareous sandstone, with abundant flakes of carbonaceous material, occurs 3 in. above lower end of core. Beds lie approximately flat. *Cleoniceras* (n. subgen.) n. sp. found at 3,249 ft was identified by Ralph W. Imlay.
----	3, 249–3, 250	No sample.
----	3, 250–3, 260	Clay shale with thin sandstone beds.
----	3, 260–3, 310	Clay shale with scattered siltstone laminae.
----	3, 310–3, 325	Sandstone, light-gray, very fine-grained, silty, argillaceous, slightly to very calcareous. Composed of subangular clear and white quartz, gray chert, and gray and black rock fragments; carbonaceous partings rare.
----	3, 325–3, 420	Clay shale with siltstone laminae.
----	3, 420–3, 430	Clay shale with sandstone and siltstone interbedded.
----	3, 430–3, 530	Clay shale with thin beds and laminae of siltstone.
----	3, 530–3, 540	Clay shale with rare siltstone laminae.
12	3, 540–3, 550	No recovery.
13	3, 550–3, 560	Recovered 2 ft 6 in.: Microfossils common. Clay shale, medium-dark-gray, noncalcareous, with rare laminae and thin lenses of medium-light-gray argillaceous siltstone. Dip less than 3°.
----	3, 560–3, 804	Clay shale, medium-dark- to dark-gray, slightly micaceous, with rare siltstone laminae.
14	3, 804–3, 807	Recovered 2 ft: Microfossils rare. Clay shale, medium-gray to medium-dark-gray, noncalcareous, with laminae and thin (less than 2 in.) beds of medium-light-gray sandy argillaceous slightly calcareous (dolomitic?) siltstone, with partings of medium-dark-gray clay shale. Dip less than 2°. Siltstone totals 15 percent of recovered core.
----	3, 807–3, 810	No sample.
----	3, 810–3, 870	Clay shale, medium-dark- to dark-gray, slightly micaceous, with rare laminae of medium- to medium-light-gray siltstone.
----	3, 870–3, 900	Clay shale with thin beds and laminae of siltstone. Top of Oumalik formation at 3,900 feet.
----	3, 900–4, 100	Clay shale, medium-dark-gray, slightly silty, noncalcareous, with siltstone laminae.
15	4, 100–4, 110	Recovered 8 in.: Microfossils absent. Claystone, medium-dark-gray, slightly silty, micaceous, noncalcareous; conchoidal fracture.
----	4, 110–4, 345	Clay shale as above, with very rare siltstone laminae.
16	4, 345–4, 348	Recovered 3 ft: Microfossils very rare. Clay shale, medium-dark-gray, slightly micaceous, noncalcareous, with some laminae of light-gray siltstone. Beds dip 3°.
----	4, 348–4, 632	Clay shale as above, dark-gray; micaceous in part, with very rare siltstone laminae and thin bed of very fine-grained sandstone at 4,550 ft.
17	4, 632–4, 635	Recovered 3 ft: Microfossils very rare. Clay shale, medium-dark-gray, noncalcareous, with very rare slightly silty medium-gray laminae of siltstone. Beds have excellent shaly cleavage and dip 2°.
----	4, 635–4, 785	Clay shale as in core 17.

Lithologic description—Continued

Core	Depth (feet)	Description
18	4, 785–4, 790	Recovered 5 ft: Microfossils absent. Clay shale, medium-dark-gray, slightly micaceous, noncalcareous, with poor shaly cleavage, dipping 3°–7° (?). Laminae of medium-gray argillaceous siltstone rare; small pyrite nodules very rare.
----	4, 790–4, 895	Clay shale as in core 18.
19	4, 895–4, 899	No recovery.
20	4, 899–4, 902	Recovered 2 ft 6 in.: Microfossils absent. Clay shale, medium-dark-gray, slightly micaceous, noncalcareous, with poor shaly cleavage dipping 3°–6° (?). Laminae and thin beds (less than one-half inch thick) of medium-light-gray argillaceous siltstone make up less than 5 percent of the rock.
----	4, 902–5, 005	Clay shale as in core 20.
21	5, 005–5, 010	Recovered 1 ft 2 in.: Microfossils absent. 5 in., sandstone, medium-light-gray, very fine-grained, very silty and argillaceous, slightly calcareous, with irregular intercalations and streaks of medium-dark-gray clay shale totaling about a quarter of the rock. 9 in., clay shale fragments, medium-dark-gray, very slightly micaceous, noncalcareous.
22	5, 010–5, 016	Recovered 6 in.: Microfossils absent. Fragments of dark-gray clay shale and medium-light-gray sandstone as above.
----	5, 016–5, 091	Clay shale as in core 24 below.
23	5, 091–5, 094	No recovery.
24	5, 094–5, 098	Recovered 4 in.: Microfossils absent. Clay shale, medium-dark-gray, slightly silty, micaceous (largely biotite), noncalcareous, with minute flakes of carbonaceous material scattered throughout. Beds approximately flat lying.
----	5, 098–5, 183	Clay shale as in core 24, with laminae medium- to medium-light-gray siltstone and rare laminae very fine-grained silty sandstone.
25	5, 183–5, 193	Recovered 9 ft: Microfossils absent. 9 in., claystone, medium-dark-gray, very slightly silty, noncalcareous, with flakes of biotite and carbonaceous material scattered throughout. Top one-half inch of rock medium-light-gray very fine-grained very silty argillaceous noncalcareous sandstone, with sharp sandstone and clay contact dipping 18°. 3 in., sandstone, medium-light-gray, very fine-grained, very silty and argillaceous, slightly micaceous, noncalcareous; rarely cross-bedded, with some bedding planes and minute tension cracks marked by a concentration of dark carbonaceous (?) material. 2 in., clay shale, medium-dark-gray, silty, micaceous, with intercalations of medium-light-gray silty argillaceous sandstone at base. 3 ft 2 in., sandstone, medium-light- to light-gray, very fine-grained, very silty and argillaceous, slightly calcareous in part; composed of subangular to angular grains of clear or white quartz, some dark grains, and a few flakes of mica and carbonaceous material. Possible cross-bedding plane (marked by slightly lighter color and coarser texture) dips 25°. Contemporaneous deformation marked by distorted partings of medium-dark-gray clay. Thin intraformational conglomerate of medium-dark-gray clay shale at 5,186 ft. 1 ft 6 in., interbedded and interlaminated clay shale and very fine-grained sandstone as above, with irregular lenses of clay; crossbedded; some beds distorted contemporaneously with deposition. 3 ft 2 in., sandstone, very fine-grained, very silty and argillaceous, as above, in part with abundant laminae and thin beds of clay distorted contemporaneously with deposition. These alternate and intergrade with sections that have subparallel carbonaceous partings spaced from 1 mm to 1 cm apart, which dip 28°–33°; some are offset by small (as much as one-half inch displacement) reverse faults.
----	5, 193–5, 268	Clay shale, medium-dark-gray, partly slightly silty, micaceous, noncalcareous, with laminae of siltstone and very fine-grained very silty sandstone; pyrite very rare.
26	5, 268–5, 278	No recovery.
27	5, 278–5, 288	No recovery.
----	5, 288–5, 360	Clay shale, medium-dark-gray, with laminae of siltstone and medium-light-gray very fine-grained silty argillaceous calcareous sandstone; slight increase in siltstone in lower 20 ft.

Lithologic description—Continued

Core	Depth (feet)	Description
28	5, 360–5, 365	Recovered 2 ft 6 in.: Microfossils absent. Claystone, grading to clay shale, medium-dark- to dark-gray, finely micaceous, with some laminae and small lenticles of medium-light-gray argillaceous noncalcareous siltstone; some laminae slightly distorted or broken with minute "step" faults. Dip of siltstone laminae is 2°–30°; dip of shaly cleavage 8° or less.
29	5, 365–5, 370	Recovered 6 in.: Microfossils absent. Claystone, medium-dark-gray, finely micaceous in part.
30	5, 370–5, 375	Recovered 2 ft: Microfossils absent. Claystone, medium-dark-gray, with subconchoidal fracture; lenticles and laminae of medium-gray silty clay and medium-light-gray siltstone rare.
----	5, 375–5, 475	Clay shale as in core 30 above with rare pyrite.
31	5, 475–5, 480	Recovered 5 ft: Microfossils absent. Clay shale, medium-dark-gray, finely micaceous, with laminae and partings of medium-gray silty clay shale and medium-light-gray siltstone; some of rock crossbedded. Beds with very good shaly cleavage dip under 1°.
----	5, 480–5, 540	Clay shale as in core 31 above.
----	5, 540–5, 575	Clay shale with thin beds sandstone, light-gray, very fine-grained, silty, argillaceous, micaceous, partly calcareous; grains composed of subangular white quartz with some white and gray chert and rare black rock fragments; contains clay laminae.
32	5, 575–5, 582	Recovered 7 ft: Microfossils absent. Claystone, medium-dark-gray, finely micaceous; irregular fracture; at 5,577 ft is 2 in. of distorted interbedded medium-light-gray siltstone and medium-dark-gray clay shale; at 5,578 ft is 6 in. of thin siltstone beds with clay laminae, showing distorted bedding, an intraformational conglomerate of siltstone fragments, and small normal faults (up to ½-in. displacement) which outline slumped blocks 1–2 in. in diameter.
----	5, 582–5, 680	Clay shale as in core 32 above (with sandstone beds in the lower 15 ft); pyrite common in sample at 5,290 ft.
----	5, 680–5, 681	No sample.
33	5, 681–5, 688	Recovered 6 ft 6 in.: Microfossils absent. Claystone, medium-dark-gray, slightly micaceous, noncalcareous; irregular

Lithologic description—Continued

Core	Depth (feet)	Description
		fractures commonly have slickensided surfaces. A 6-in. section at 5,685 ft has laminae and thin beds of siltstone and medium-light-gray very fine-grained micaceous very slightly calcareous silty sandstone; some distortion probably due to contemporaneous deformation.
----	5, 688–5, 690	No sample.
----	5, 690–5, 780	Clay shale with thin, very silty beds of sandstone at 5,700, 5,720, and 5,730 ft, and siltstone and silty argillaceous sandstone laminae.
34	5, 780–5, 790	Recovered 6 in.: Microfossils absent. Claystone, medium-dark-gray, very slightly micaceous, with subconchoidal fracture; rare laminae of medium-gray silty clay shale.
35	5, 790–5, 795	No recovery.
36	5, 795–5, 800	Recovered 8 in.: Microfossils absent. Clay shale similar to the claystone in core 34, but with poor shaly cleavage.
37	5, 800–5, 802	Recovered 2 ft: Microfossils absent. Clay shale, medium-dark-gray, finely micaceous, noncalcareous, with good shaly cleavage. Dip as much as 3°. Interbedded laminae and thin beds of medium-light-gray partly slightly sandy micaceous very slightly calcareous siltstone, with some crossbedding, total a third of core.
----	5, 802–5, 860	Clay shale with siltstone as in core 37 above.
38	5, 860–5, 865	Recovered 2 ft 6 in.: Microfossils absent. Claystone and clay shale, medium-dark-gray, very slightly micaceous, noncalcareous; with a few laminae of medium-gray silty clay shale, distorted (probably by contemporaneous slumping) in upper part. Dip of undisturbed laminae in lower part 3°.
----	5, 865–5, 944	Clay shale as in core 38.
39	5, 944–5, 954	Recovered 9 ft: Microfossils absent. 8 ft, clay shale, medium-dark-gray, irregularly interlaminated with medium-light-gray siltstone with clay forming about two-thirds of the sediment. Very good shaly cleavage dips about 2°. Some silt laminae thicken abruptly to lenses about one-fourth inch thick. 1 ft, siltstone, medium-gray, sandy, argillaceous, slightly calcareous; a vertical calcite veinlet cuts through bottom 3 in. of core.

Lithologic description—Continued

Core	Depth (feet)	Description
40	5, 954–5, 964	Recovered 10 ft: Microfossils absent. 7 ft, interbedded laminae and thin beds of medium-dark-gray noncalcareous micaceous clay shale and medium-light-gray sandy argillaceous slightly calcareous siltstone containing rare carbonaceous flakes. Beds approximately flat lying. 3 ft, sandstone, medium-light-gray, very fine-grained, very silty and argillaceous, micaceous (largely biotite), very slightly calcareous, with flakes of carbonaceous material (probably carbonized plant remains) scattered throughout. Faint odor of oil noted.
41	5, 964–5, 967	Recovered 2 ft 6 in.: Microfossils absent. Sandstone as above, but with abundant carbonaceous partings in top 6 in., and clay laminae and lenses at 5,965 ft.
42	5, 967–5, 974	Recovered 4 ft 3 in.: Microfossils absent. Sandstone, medium-gray, very fine-grained, silty, argillaceous, slightly calcareous, well-indurated. Faint oil odor present; pale-yellow cut and clear yellow residue in CCl_4. Sand grains angular, white and clear quartz, frosted in part, and commonly have a slight brownish (bituminous?) surface stain. Rare grains of gray rock fragments and coal particles also present. At 5,972 ft effective porosity 10 percent, but rock is impermeable to air. Carbonate content 2.2 percent by weight.
43	5, 974–5, 984	Recovered 2 ft: Microfossils absent. Sandstone as above.
44	5, 984–5, 990	No recovery.
45	5, 990–6, 000	Recovered 8 ft: Microfossils absent. Claystone, medium-dark-gray, micaceous, noncalcareous, with numerous laminae of medium-gray silty clay that dip approximately 10°. Vertical smooth-surfaced fractures splitting sections of core into subequal parts are common. Claystone becomes slightly silty with depth, and 5,998–5,999 ft is dominantly siltstone, although containing some intercalations of clay.
----	6, 000–6, 003	Depth corrected from 6,000 to 6,003 feet.
46	6, 003–6, 013	Recovered 8 ft 6 in.: Microfossils absent. Clay shale, medium-dark-gray, micaceous, noncalcareous, with laminae and thin beds of medium-gray silty clay shale and siltstone which are commonly crossbedded. Vertical smooth-surfaced fractures common, as in core 45 above.
47	6, 013–6, 023	Recovered 10 ft.: Microfossils absent. Claystone, medium-dark-gray, silty, very micaceous, noncalcareous; lithology very uniform except for 2-in. section (at 6,018 ft) of siltstone containing somewhat distorted laminae of clay; vertical fractures, as above, common, and core from 6,017 ft to 6,018 ft has been split by two parallel vertical fractures about one-half inch apart.
48	6, 023–6, 033	Recovered 9 ft 6 in.: Microfossils absent. Clay shale, medium-dark-gray, slightly silty, finely micaceous, noncalcareous, with poor shaly cleavage, and a few vertical, smooth-surfaced fractures as in core 47.
49	6, 033–6, 043	Recovered 10 ft: Microfossils absent. 8 ft 3 in., clay shale as above. 1 ft 2 in., siltstone, light-olive-gray, slightly sandy, very slightly calcareous, micaceous, with rare carbonaceous specks. 7 in., clay shale as above.
50	6, 043–6, 052	Recovered 3 ft 10 in.: Microfossils absent. Clay shale, medium-dark-gray, slightly micaceous, noncalcareous, with good shaly cleavage. Dip 4° or less. Thin beds of medium-gray siltstone with interlaminated and commonly crossbedded clay laminae increase with depth.
----	6, 052–6, 130	Clay shale as in core 50.
----	6, 130–6, 140	Sandstone as in core 51 below.
51	6, 140–6, 150	Recovered 9 ft 6 in.: Microfossils absent. 3 ft 1 in., sandstone, olive-gray, very fine-grained, silty, argillaceous, micaceous, noncalcareous. Good oil odor. Saturation test of sample from 6,141 ft determined petroleum and water percent by volume to be 4.81 and 2.84 percent, respectively. At 6,143 ft a light fraction of petroleum made up 0.62 percent of the sample by volume; heavy fraction 2.46 percent; water content 2.15 percent of same sample. Effective porosity at 6,141 ft 11.8 percent; rock impermeable; carbonate content 10 percent by weight. Flakes and rare partings of carbonaceous material scattered throughout. Sand grains angular to subangular and commonly frosted, composed largely of clear quartz, with some white quartz and a few brown or

Lithologic description—Continued

Core	Depth (feet)	Description
		gray rock fragments. Many have a faint brownish surface stain (bitumen?). Glauconite, pyrite, and mica very rare; carbonaceous grains only slightly more common. A 1-in. bed of clay shale present at 6,142 ft. 7 in., clay shale, medium-dark-gray, micaceous, noncalcareous, with good shaly cleavage. Laminae and thin beds of siltstone, some slightly crossbedded, occur in lower half. Beds lie approximately flat. 1 in., sandstone as above. ½ in., clay shale as above. 8 in., siltstone, light-olive-gray, sandy, argillaceous, slightly calcareous, with carbonaceous flakes and partings concentrated in the upper half. 5 ft, clay shale, medium-dark-gray, micaceous, noncalcareous, with good shaly cleavage in upper 1 ft. Slightly silty toward base. Fragmental fish (?) remains and very rare flakes of bituminous material scattered throughout. Irregular band ¼–½ in. wide of medium-gray silty sandstone, dipping approximately 30°, at 6, 149 ft. Sand grains angular to subangular clear quartz, with brownish surface stain, as in sandstone above.
52	6, 150–6, 160	Recovered 9 ft 6 in.: Microfossils absent. Claystone, to clay shale, medium-dark-gray, noncalcareous, very slightly silty in part. Irregular laminae and bands of medium-gray silty sandstone and sandy siltstone, dipping as much as 35°, are present and rarely are distorted by contemporaneous deformation. One band, at 6,157 ft, is 4 in. thick, with clay laminae in it; another, at 6,159 ft is 6 in. thick and also contains clay laminae.
----	6, 160–6, 232	Clay shale as in core 52 with some siltstone beds.
----	6, 232–6, 270	Interbedded sandstone and clay shale. Sandstone is dark yellowish brown, very fine grained, and very slightly calcareous, with brown (oil?) stain. Grains angular to subangular clear quartz, with some carbonaceous particles, white quartz and dark rock fragments.
----	6, 270–6, 430	Clay shale, medium-dark-gray, nonmicaceous to very slightly micaceous, as in core 52. Slight amount of sandstone, as above, 6,340–6,350 ft. Electric log suggests presence of bed of sandstone at 6,290–6,300, but ditch samples do not contain any sandstone.
----	6, 430–6, 440	Clay shale as above, and light-yellowish-brown very fine-grained silty sandstone; grades to siltstone of same color and composition. It is finer grained, lighter in color, and tighter than sandstone at 6,240 ft.
----	6, 440–6, 480	Clay shale as above.
53	6, 480–6, 490	Recovered 7 ft 3 in.: Microfossils very rare. 1 ft 7 in., sandstone, light-olive-gray, very fine-grained, very silty and argillaceous, noncalcareous, with scattered laminae of medium-dark-gray clay. Sand grains similar in shape and composition to those in core 51. 8 in., interbedded thin beds of sandstone as above and medium-dark-gray clay shale. 1 ft 10 in., siltstone, medium-gray, very argillaceous, slightly sandy, noncalcareous; grades into unit below. 6 in., claystone, medium-dark-gray, silty; a few very silty streaks dip 15°–20°. 1 ft, interbedded sandstone and clay shale as above. 1 ft 8 in., sandstone as above.
54	6, 490–6, 500	Recovered 6 ft: Microfossils absent. 1 ft 7 in., interbedded sandstone and clay shale as above. 3 ft 6 in., sandstone, medium-gray, very fine-grained, silty, argillaceous, very slightly calcareous, very uniform. Fair oil odor; yellow cut and residue in CCl_4. Carbonaceous partings rare in bottom 3 in.; just above base of section is a ¾-in. bed of fine- to medium-grained silty sandstone with small-scale crossbedding. Plug made parallel to bedding at 6,498 ft had an effective porosity of 4.72 percent, was impermeable; rock has a carbonate content of 16.5 percent by weight. 11 in., interbedded clay shale and silty very fine-grained sandstone, as above, with silty laminae in the clay shale.
55	6, 500–6, 510	Recovered 9 ft 6 in.: Microfossils absent. Clay shale, medium-dark-gray, slightly silty, noncalcareous, very micaceous (biotite). Poor shaly cleavage. Rare flakes of bituminous and carbonaceous material scattered throughout. Beds lie approximately flat.

Lithologic description—Continued

Core	Depth (feet)	Description
----	6, 510–6, 555	Clay shale, dark-gray, very slightly silty, very slightly micaceous, noncalcareous. Electric log suggests sandstone from 6,540 to 6,547 ft.
----	6, 555–6, 575	Sandstone, very fine-grained, silty, argillaceous, very slightly calcareous; composed of angular light-brownish clear quartz.
----	6, 575–6, 590	Clay shale, medium-dark-gray.
----	6, 590–6, 620	Sandstone and clay shale as above. Top of Upper Jurassic rocks placed at 6,600 feet.
----	6, 620–6, 740	Clay shale, dark-gray; pyrite rare to abundant; waxy tan clay in some samples. Shale becomes darker with increasing depth. Biotite specks in tan waxy clay fragment at 6,740 ft. Rare rounded quartz grains as in core 56 near base of unit. Sharp lithologic break between core 55 and core 56 cannot be determined more accurately from ditch samples because of contamination of samples by caving of shale from farther up hole. Electric log suggests change in lithology near 6,700 ft.
----	6, 740–6, 743	No sample.
56	6, 743–6, 753	Recovered 2 ft 6 in.: Microfossils abundant. Clay shale, grayish-black, pyritic; shaly to subconchoidal fracture; clear quartz grains, medium to fine, rounded to very well rounded, polished or with slightly frosted or pitted surfaces, scattered singly or in small groups through shale. A 1-in. bed of medium-light-gray dense argillaceous limestone occurs 1 in. from top of recovered core.
----	6, 753–6, 849	Clay shale, dark-gray to grayish-black, hard. Pyrite and tan waxy clay common; light-greenish-gray clay fragments rare. Rare quartz grains as described in core 56 above. A 2-mm well-rounded chert granule at 6,760 ft. Rare fragments of sandstone, medium- to fine-grained, of rounded to well-rounded clear quartz and some blue-green glauconite grains, with calcareous, silty, pyritic matrix, occur from 6,790 to 6,810 ft. Pieces of shale with laminae or small concretions of pyrite rare throughout. One piece of pyrite containing brown soft well-rounded very fine-sand-size grains found at 6,830 ft. Sandstone fragment from 6,850 ft contains bituminous flakes.
57	6, 849–6, 859	Recovered 5 ft: Microfossils very rare. Clay shale, grayish-black, good shaly cleavage, with quartz grains as in core 56 above. Pyrite very rare. Carbonized plant fragment on one bedding plane. Beds approximately flat lying.
----	6, 859–6, 860	No sample.
58–60	--------------	There was no recovery from cores 58 (6,927–6,932 ft), 59 (6,932–6,942), 60 (6,942–6,950), and the following description of the no-recovery depths between 6,927 and 6,950 are from cuttings only.
----	6, 860–7, 040	Clay shale, grayish-black, hard, with abundant pyrite, in part as concretions or laminae in shale. Fragments of tan waxy clay rare to common; rare to abundant rounded clear quartz grains and a few granules of black chert are present; fragments of very fine-grained brown sandstone and siltstone are common. Slickensides on shale fragments from 6,890 ft, 6,900 ft, and 6,930 ft; tan waxy clay with mica particles occurs as laminae in black shale fragment from 6,880 ft. Brown limestone fragments found at 6,880 ft and 6,940 ft; a fragment at 6,880 ft has a 0.5 mm veinlet of dark-brown quartz. Brown very fine-grained sandstone laminae present in black shale fragments at 6,900 ft and 6,940 ft. "Sandstone" made of well-rounded to very well-rounded medium to very fine grains of clear quartz and blue-green glauconite in black shale matrix common in most samples below 6,930 ft; it forms 5 percent of samples at 6,960 ft and 6,980 ft; 25 percent of sample at 6,950 ft composed of black shale fragments with sand grains scattered through them. Greenish-gray waxy clay present at 6,970 ft. One piece of shale at 6,980 ft grades from grayish-black to brownish-black with bituminous (?) flakes. One piece of sandstone at 7,000 ft has bituminous flakes.
----	7, 040–7, 042	No sample.
61	7, 042–7, 052	Recovered 3 ft: Microfossils very abundant. 1 ft 9 in., claystone, grayish-black, pyritic, with rounded fine to medium sand grains of clear quartz as described in core 56 above. 1 ft 3 in., clay shale, grayish-black. slightly micaceous, pyritic, with quartz grains as described above, Good shaly cleavage; beds lie approximately flat.

Lithologic description—Continued

Core	Depth (feet)	Description
62	7, 052–7, 062	Recovered 5 ft: Microfossils very abundant. Clay shale as above. Pelecypod shells, including a specimen at 7,060 ft, which was identified by Ralph W. Imlay as *Aucella* cf. *A. rugosa* (Fischer), with rare fragments throughout recovered core.
----	7, 062–7, 804	Clay shale, grayish-black, hard, as in core 62 above, with rare pyrite; rare rounded clear quartz grains from 7, 062 to 7,550 ft; common to abundant quartz grains from 7,550 to 7,760 ft. Coarse to fine well-rounded sand of clear quartz and glauconite in black shale matrix common to 7,340 ft, rare from 7,340 to 7,760 ft. Black shale with abundant blue-green glauconite grains, but no quartz, is rare to common, increasing with depth. From 7,560 to 7,760 ft very fine sand grains of white quartz and small amount of white calcite, angular to subangular, range from rare to abundant and increase with depth. Loose glauconite grains common from 7,630 to 7,760 ft. Brown limestone common at 7,360 to 7,370 ft. Two fragments of large subangular quartz (?) grains in pyrite matrix found at 7,550–7,560 ft. Ditch samples below 6,100 ft probably badly contaminated by cavings and do not represent accurately depths from which taken. Electric log shows pattern typical of shale down to 7,760 ft. From 7,760 to 7,804 ft, however, is an abrupt large increase in spontaneous potential, matched by a smaller but equally sudden increase in resistivity. Neither are reflected in samples, which contain nothing but black shale through this depth, but curves may reflect change in lithology from shale to type of rock described in core 63.
63	7, 804–7, 814	Recovered 10 ft: Microfossils absent. Glauconite sandstone, grayish-black, argillaceous, hard, massive. As seen in thin section, it is composed of approximately 75 percent medium to very fine well-rounded grains of grayish-green glauconite. Matrix largely black clay but contains very fine subangular quartz grains. Many of the glauconite grains have brownish rims, and some seem to be largely altered to brownish material. Two or three similarly shaped grains consist of yellow earthy mineral, and one is reddish; these may be limonite and hematite, respectively. Granular to flaky shiny red mineral, probably hematite, is scattered through core. Abundance of glauconite and hematite vary, with former decreasing and latter increasing to 40 percent in some sections. Hematite-rich fragment has specific gravity of 3.35.
----	7, 814–7, 829	Gray and black shale. Top of Middle Jurassic rocks at 7,820 ft.
64	7, 829–7, 839	Recovered 10 ft: Microfossils absent. 5 ft, siltstone, medium-gray, argillaceous, well-indurated, very slightly micaceous, noncalcareous, with abundant irregular laminae of dark-gray clay totaling about 25 percent of the rock. Grades into unit below. 5 ft, siltstone as above but medium-light-gray; lighter color due to decrease in clay laminae, which are a minor constituent. Effective porosity of sample from 7,835 ft 6.4 percent; air permeability less than 1 millidarcy.
65	7, 839–7, 849	Recovered 8 ft 4 in.: Microfossils absent. Siltstone with clay intercalations as above.
66	7, 849–7, 857	No recovery.
----	7, 857–8, 020	Siltstone as in cores 63 and 64 above, probably with some black and gray shale. Well cuttings composed almost entirely of black shale, most of which probably caved from overlying beds.
----	8, 020–8, 104	Clay shale, black and medium-dark-gray, with rare pyrite. Electric log has curve typical of shale, except for some small sharp curves in resistivity between 8,035 and 8,060 ft. No material found in ditch samples to account for these sharp "kicks"; much of the rock in the samples may be contamination from above.
67	8, 104–8, 114	Recovered 7 ft 6 in.: Microfossils absent. Clay shale, medium-dark-gray, finely micaceous, noncalcareous, fair shaly cleavage. Beds lie flat. Minute streaks and lines of pyrite common throughout. Middle Jurassic ammonites (*Pseudolioceras?* sp. and *Tmetoceras* sp.) identified by Ralph W. Imlay (1955, p. 82, p. 89).
----	8, 114–8, 215	Clay shale, some similar to core 67, with rare light-gray and brown sandstone and siltstone at top.
----	8, 215–8, 275	Siltstone, medium-gray, very argillaceous, with some clay shale.

Lithologic description—Continued

Core	Depth (feet)	Description [1]
		3 ft 9 in., claystone, dark-gray, very silty, very siliceous, noncalcareous, with scattered minute carbonaceous and pyritic patches, increasing in size with depth. Irregular to subconchoidal fracture.
		1 ft 7 in., claystone, medium-gray, silty, very siliceous, noncalcareous, with small scattered sandy patches in upper part, and some small medium-dark-gray patches of carbonaceous material.
		9 in., claystone as above, very silty, mottled grayish-red, which increases with depth.
		8 in., claystone as above, but grayish-red throughout, grades into unit below.
		1 ft, claystone as above, with gray and red marbled appearance.
		3 in., claystone, medium-light-gray, with some small red patches, very siliceous, noncalcareous, with rare silt and sand grains and rare faint slickensides.
		6 in., claystone, marbled grayish-red and gray, silty, siliceous.
		6 in., claystone, medium-light-gray, nonsilty, siliceous, slightly waxy appearance.
		1 ft 1 in., sandstone, very fine- to fine-grained, silty, slightly siliceous, argillaceous, noncalcareous; grades into unit below.
		6 in., conglomeratic sandstone, medium- to medium-dark-gray, fine- to medium-grained, silty, siliceous, with scattered subround black chert pebbles up to one-half inch diameter, and small dark-gray carbonaceous patches.
		6 in., sandstone as in interval overlying conglomeratic sandstone.
----	9, 522–9, 523	No sample.
78	9, 523–9, 538	Recovered 15 ft: Not sampled for microfossils.
		1 ft 5 in., (3 in.), conglomerate, light-gray, with white, gray, and altered, chalky-appearing chert pebbles up to one-fourth inch in diameter in a matrix of coarse to fine clear quartz sand with siliceous cement.
		1 ft 3 in., (6 in.), sandstone, light-gray, fine- to medium-grained, very siliceous; composed of subround to angular clear quartz and white chert grains with very rare subangular white chert pebbles up to one-fourth inch in diameter. Contact with conglomerate above and below irregular, but not gradational.
		4 ft 8 in., (5 in.), conglomerate, light-gray. An ill-defined band, about 1 in. wide, half pebbles and half sandstone matrix, marks change from sandstone to conglomerate. Pebbles and matrix in this upper 1 in. are similar to those of conglomerate below, difference being in their proportions. Conglomerate pebbles predominantly white chert, commonly altered (before deposition in the conglomerate) to a chalky appearance, though hardness has not been appreciably affected. About 20 percent of the pebbles are black and gray chert; 1 or 2 light-green chert pebbles and a few gray or brownish-gray siliceous siltstone pebbles also present. Chert ranges in size from granules to pebbles three-fourths inch in diameter, though most pebbles are between one-eighth inch and one-fourth inch across; they are angular to subrounded, and usually of low sphericity. Most of the sand is fine to coarse and is of clear and white quartz and a small amount of chert in a siliceous matrix that constitutes 25 percent of the rock.
		6 in., (6 in.), sandstone, light-gray, very fine- to coarse-grained, conglomeratic, siliceous, with scattered chert pebbles up to one-eighth inch in diameter, especially in lowest 1 in.
		1 in., (1 in.), sandstone as in 1 ft 3 in. unit above; grades into unit below.
		1 in., (1 in.), sandstone as in 6 in. unit above; grades into unit below.
		2 ft 8 in., (11 in.), conglomerate, with white, black, and gray chert pebbles up to 1 in. in diameter (average about one-half inch in diameter), subround to well rounded, of low sphericity, with a few rounded siliceous sandstone and siltstone pebbles. Matrix constitutes approximately 15 percent of the rock, and is composed of fine to coarse grains of clear and white quartz, with some chert, and siliceous cement.

See footnote at end of table.

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Lithologic description—Continued

Core	Depth (feet)	Description [1]
		3 in., (3 in.), conglomerate as above but with 70 percent of matrix, 30 percent of pebbles; pebbles rarely more than one-half inch in diameter. 1 in., (1 in.), conglomerate as above, but pebbles more numerous (up to 50 percent of the rock) and larger (as much as 1 in. in diameter). 1 ft (1 ft), conglomerate as above, but with pebbles averaging one-fourth inch in diameter, largest being three-fourths inch; matrix fine to coarse sand with siliceous cement and microscopic, bipyramidal, euhedral quartz crystals occurring as "sugary" interstitial material. Base of conglomerate, as received in Fairbanks laboratory, has a thin coating of dark-gray clay which may mark contact with underlying sediments. 3 ft, (11 in.), sandstone, with streaks of siltstone and thin (less than one-half inch thick) beds of clay shale. Sandstone medium light gray, fine to coarse grained, and composed of subangular to subround clear quartz with rare white chert, and siliceous cement. Siltstone streaks numerous and similar to sandstone in color and content, differing only in grain size. Clay shale also medium light gray and siliceous, with faint laminae which indicate that beds lie approximately flat. It is silty and slightly sandy and grades to the coarser material; makes up about 10 percent of part received.
----	9, 538–9, 539	No sample.
79	9, 539–9, 557	Recovered 18 ft: Microfossils absent. 3 ft, (1 ft 4 in.), siltstone, medium-light-gray, very sandy, very siliceous; irregular to subconchoidal fracture. A 2-in. bed of medium-light-gray siliceous claystone, with a waxy appearance and conchoidal fracture, 1 ft below top. 1 ft 6 in., (2 in.), claystone as described in siltstone unit above. 3 ft 6 in., (3 ft 6 in.), sandstone, light-gray, fine-grained; composed of clear quartz grains with siliceous cement, part of which is white, amorphous, and softer than chert. Amount of amorphous cement and grain size increase gradually with depth. Vertical and irregular horizontal (bedding plane?) fractures present; latter more numerous toward bottom of unit. 4 in., (4 in.), conglomerate of subrounded to angular pebbles $\frac{1}{16}$–2 in. in diameter; composed of very fine-grained clear quartz sandstone with much white, soft, siliceous, microcrystalline (?) cement. Pebbles held in matrix of fine- to coarse-grained clear and smoky quartz with silica cement, which is harder than the pebbles and constitutes about 50 percent of the rock. 9 ft 8 in. (4 ft 8 in.), sandstone, light-gray, fine-grained, very siliceous, with some amorphous white cement. Sandstone is massive and has vertical fractures and some laminae of slightly finer slightly carbonaceous sandstone. Thin bed of silty siliceous claystone, one-fourth inch thick, occurs 7 ft 2 in. below top of unit and was deposited on an undulating surface that may represent a wide, shallow ripple mark. Sandstone below claystone very slightly darker, slightly more siliceous, and has less white, amorphous cement than that above.
80	9, 557–9, 568	Recovered 11 ft: Not sampled for microfossils. 1 ft, (4 in.), sandstone as above. 10 ft, (4 ft 8 in.), sandstone, medium-gray, very fine-grained, very siliceous, with $\frac{1}{4}$-in. beds of medium-gray siliceous clay shale 1 ft and 4 ft 8 in. below top of unit. Sandstone has slight range in color, becoming very slightly darker when siltier, lighter when sand grains are larger. White amorphous cement of sandstone above is absent.
----	9, 568–9, 574	No sample.
81	9, 574–9, 597	Recovered 23 ft: Microfossils absent. 16 ft 3 in., (3 ft 4 in.), sandstone, light- to medium-light-gray, very fine-grained, slightly to very silty, very siliceous, noncalcareous; siltier sections slightly darker than coarser grained units. Two $\frac{1}{4}$-in. beds of medium-dark-gray siliceous argillaceous approximately flat-lying siltstone occur in basal 1 ft. 10 in., (10 in.), clay shale, dark-gray, nonsiliceous, nonmicaceous, noncalcareous, with scattered streaks of pyrite and laminae of silt containing some angular sand grains. Subconchoidal to shaly fracture.

See footnote at end of table.

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Lithologic description—Continued

Core	Depth (feet)	Description [1]
		7 in., (7 in.), siltstone, medium-dark-gray, sandy, slightly carbonaceous, very siliceous, noncalcareous, with some clay shale as above. 3 in., (3 in.), clay shale as above. 11 in., (11 in.), siltstone as above but with less clay shale. 1 ft 9 in., (1 ft 9 in.), clay shale as above, with beds (as much as one-half inch thick) of siltstone; cross-bedding and distorted bedding in lower 5 ft. 9 in., (9 in.), siltstone as above. 1 ft. (1 ft), claystone, similar to clay shale above but lacking siltstone laminae; has conchoidal fracture and some polished surfaces, in part marked by slickensides. 8 in., (8 in.), interbedded siltstone and clay shale, with ½-in. layer of intraformational conglomerate composed of flat rounded shale pebbles in light-gray sandy siliceous matrix at top and a few similar pebbles in base of sandy siltstone bed 6 in. below top.
----	9, 597–9, 770	Interbedded siliceous sandstone, siltstone, and claystone, as in cores above; many fragments have carbonaceous partings.
----	9, 770–9, 795	Claystone, red, silty, with some red siltstone. Top of red beds at 9,770 feet.
----	9, 795–9, 816	Sandstone, red, very fine- to fine-grained, nonmicaceous, very calcareous.
82	9, 816–9, 821	Recovered 5 ft: Microfossils absent. Claystone, grayish-red, commonly silty, very slightly sandy, very finely micaceous, noncalcareous; poor to good shaly cleavage; streaks and irregular beds (as much as 3 in. thick) of grayish-red to light-gray very fine-grained silty slightly to very calcareous siltstone and sandstone. Sand grains clear subangular to subround quartz, with rare colored (reddish, black, green) grains, and hematitic (?) and calcareous cement. Beds lie approximately flat.
----	9, 821–9, 845	Sandstone, brick-red, very fine-grained, silty, with small amount of light-red very slightly silty nonmicaceous calcareous sandstone.
----	9, 845–9, 900	Sandstone, claystone, and siltstone, all light- and dark-red, with interlaminated red and light-grayish-green silty partly calcareous claystone.
----	9, 900–9, 940	Sandstone, red, as above, with streaks of red chert conglomerate (pebbles as much as one-fourth inch in diameter, possibly larger), increasing with depth, and minor amount of red claystone and very rare greenish-gray claystone; chert grains in conglomerate are red, grayish green, and gray.
----	9, 940–9, 980	Alternating red sandstone and claystone, and red and green clay shale.
----	9, 980–9, 990	Limestone, blue-gray, very slightly argillaceous, dense, with minute calcite veinlets.
----	9, 990–10, 007	Sandstone, red, with small amount of red claystone as above.
83	10, 007–10, 017	Recovered 3 in.: Microfossils absent. Conglomerate of subangular pebbles of red, black, and light-gray chert, ranging from granules to three-fourths inch in diameter, with most 1/16–¼ in. in diameter. Matrix, which makes up small proportion of the rock, contains coarse chert sand, subrounded clear quartz sand and silt, and calcareous and hematitic cement. No bedding visible, though long axes of pebbles usually are horizontal.
84	10, 017–10, 022	Recovered 3 in.: Microfossils absent. Siltstone, grayish-red, very sandy, very argillaceous, noncalcareous, with hematitic cement. Sand grains mostly reddish (from surface stain?) quartz, subrounded, commonly with with frosted surfaces. Angular clear quartz, white quartz, and white chert grains also present.
----	10, 022–10, 040	Sandstone, red, with minor amount of claystone and chert as in ditch samples above.
---	10, 040–10, 190	Chert conglomerate, dark-gray, and black carbonaceous claystone and clay shale as in cores 86–100. Samples contaminated with red sediments from above. No sample received for depths between 10,078 and 10,083 ft. Top of Middle (or Lower?) Devonian rocks at 10,040 ft.
----	10, 190–10, 195	Coal seam, black, subvitreous, hard.
----	10, 195–10, 228	Chert conglomerate, dark-gray, with small amount black claystone near base.
85	10, 228–10, 229	Recovered 1 ft 3 in.: Microfossils absent. Chert conglomerate, medium-gray, very sandy, siliceous. Pebbles range from 1/16 to ½ in. in diameter, but most are from ⅛ to ¼ in.; some scattered through coarse- to fine-

See footnote at end of table.

Lithologic description—Continued

Core	Depth (feet)	Description[1]
		grained sandy matrix, and some concentrated in thin irregular layers; composed of subangular white, gray, and black chert. Matrix consists of subangular coarse to very fine grains of same composition, with some silty and argillaceous interstitial material; whole is well cemented by additional silica. Darker, shalier streaks, commonly with carbonaceous films marking partings, dip approximately 35° and are subparallel to conglomeratic beds. A few small milky quartz veinlets cut across matrix and pebbles. Minute cubes and irregular patches of pyrite also present in matrix and pebbles.
----	10, 229–10, 384	Alternating dark-gray chert conglomerate and black carbonaceous claystone as in cores 87–100.
86	10, 384–10, 385	No recovery.
87	10, 385–10, 390	Recovered 5 ft: Not sampled for microfossils. Chert conglomerate, medium-gray, composed of subround to subangular pebbles 1/16–1 in. in diameter (average 1/4–1/2 in.), with siliceous, argillaceous cement. Chert predominantly gray, with about 30 percent of black and a few green pebbles, and a few fragments of grayish-black claystone which is partly carbonaceous. Quartz veinlets, many of which cut across pebbles, and a few minutely faulted, are abundant; rare crystals of unidentified mineral resembling spinel occur with euhedral quartz crystals in veins. Minute patches of pyrite also present. Examination of hand specimens from cores below 10,385 ft and thin sections from 10,395 ft and 10,400 ft shows no evidence of metamorphism in these rocks. No alteration of original sediments has taken place, and quartz grains show no evidence of strain. Delicate structures in plant fragments preserved intact.
88	10, 390–10, 403	Recovered 13 ft: Microfossils absent. 2 ft, conglomerate as above. 1 ft, sandstone, medium-dark-gray, fine- to medium-grained, slightly silty, very siliceous, noncalcareous; composed of subround to subangular grains of chert; except for grain size, very similar to conglomerate described below. 3 ft, chert conglomerate; composed of subangular to subrounded well-sorted pebbles 1/16–3/4 in. in diameter, mostly 1/16–1/4 in. Coarser sizes concentrated in thin irregular beds grading to finer grained beds above and below; dip approximately 50°. About 20 percent of chert pebbles are green or gray green; 25 percent black; remainder medium- to light-gray. Quartz grains rare; other minerals and rock fragments very rare. Thin section shows grains tightly packed and deposition of additional chert and quartz around grains has left very little space; this is filled with fine quartz silt. Quartz veinlets present, and a few of them continue across pebbles. 7 ft, claystone, grayish-black, slightly silty, slightly siliceous, nonmicaceous, noncalcareous, with minute discontinuous carbonaceous partings. Irregular fractures common—most have shiny carbonaceous surface film; many show slickensides. Short narrow quartz veinlets with euhedral crystals (and scattered crystals of an unidentified mineral resembling spinel) are present, as are small rare patches of pyrite. Dip of 50°–60° shown by thin slightly lighter-colored layers of siltier material; bedding somewhat irregular.
89	10, 403–10, 412	Recovered 9 ft: Microfossils absent. Claystone as above, but siltier and slightly lighter (dark-gray) in color. Fractures and veinlets less common.
----	10, 412–10, 417	No sample.
----	10, 417–10, 433	Predominantly dark-gray chert conglomerate in one-third at top, with black claystone in two-thirds at bottom.
90	10, 433–10, 450	Recovered 17 ft: Microfossils absent. 17 ft, (10 ft), claystone, dark-gray, slightly silty in part, noncalcareous, with subconchoidal fracture. Many fragments have shiny black carbonaceous surfaces, commonly with slickensides. Partings covered with fragmental carbonized plant remains are common and are abundant at 10,441 ft. Irregular bed, 1 in. thick, of medium-gray very fine-grained siliceous sandstone occurs 1 ft above base of core; top one-fourth inch contains discontinuous pyrite layer. Pyrite nodules

See footnote at end of table.

Lithologic description—Continued

Core	Depth (feet)	Description [1]
		¼–1 in. in diameter present on 1 or 2 bedding planes. Between 10,436 and 10,437 ft is a 7-in. band of siltstone, slightly lighter in color than the claystone; claystone immediately below has carbonaceous partings with distorted bedding indicative of contemporaneous slumping. Dip approximately 35°. Fragmental remains of primitive plants found at 10,441 ft identified by James M. Schopf as *Psilophyton* n. sp., near *P. princeps* Dawson, *Zosterophyllum?* n. sp., *Aphyllopteris* sp., and *Hostimella?* sp. (written communication, 1951).
91	10, 450–10, 460	Recovered 7 ft: Microfossils absent. 4 ft 6 in. (2 ft), claystone as in core 90 above, with bands of siltstone in lower part. 2 ft 6 in. (2 ft 6 in.), chert conglomerate as in lower part of core 88, becoming coarser and less well sorted with depth.
92	10, 460–10, 461	No recovery.
93	10, 461–10, 468	Recovered 6 ft: Microfossils absent. 1 ft 6 in. (1 ft. 6 in.), chert conglomerate as at base of core 91. 3 ft 6 in. (2 ft. 6 in.), claystone as in core 90 above. 1 ft (1 ft), chert conglomerate as above.
----	10, 468–10, 469	No sample.
94	10, 469–10, 472	Recovered 1 ft 8 in.: Not sampled for microfossils. Chert conglomerate as in core 88, with about 10 percent of pebbles somewhat larger than 1 in. in diameter. One or two of the rare black claystone pebbles have slight surface indentations, caused by pressure of small adjacent chert pebbles.
95	10, 472–10, 476	Recovered 2 ft: Not sampled for microfossils. Chert conglomerate as in core 88, but with some subrounded pebbles 2–2½ in. in diameter. Pebbles nearly equidimensional and show no particular orientation. Black shale pebbles have been pressed against the harder chert pebbles and many edges on the black shale pebbles slightly curved to conform to outline of chert pebbles.
96	10, 476–10, 479	Recovered 3 ft: Not sampled for microfossils. Chert conglomerate as in core 88.

See footnote at end of table.

Lithologic description—Continued

Core	Depth (feet)	Description [1]
97	10, 479–10, 486	Recovered 6 ft (4 ft): Not sampled for microfossils. Chert conglomerate as in core 88.
98	10, 486–10, 487	Recovered 1 ft: Not sampled for microfossils. Chert conglomerate as in core 88.
99	10, 487–10, 500	Recovered 11 ft: Not sampled for microfossils. 2 ft (2 in.), chert conglomerate as in core 88; in sharp contact with 1 ft 2 in. (1 ft 2 in.), siltstone, medium-dark-gray, slightly sandy, siliceous, argillaceous, noncalcareous; sharp but irregular contact with underlying claystone dips approximately 40°. 2 ft 4 in. (2 ft 4 in.), claystone, dark-gray, hard, with streaks of nodular pyrite parallel to bedding planes, which dip about 40°. 5 ft 6 in. (1 ft 4 in.), chert conglomerate as in core 88.
100	10, 500–10, 506	Recovered 5 ft: Not sampled for microfossils. Chert conglomerate as in core 88.
	NOTE	Total depth of well corrected by the drillers to 10,503 from 10,506.
101	10, 503	No penetration; 1 ft recovered from core 100; chert conglomerate as in core 88.

[1] To avoid excessive shipping weight, only representative parts of the cores described below were sent to the Fairbanks laboratory; the thickness of the sample received is given in parentheses after that of the core it represents.

HEAVY-MINERAL ANALYSIS

Heavy-mineral samples prepared in the Fairbanks laboratory were analyzed by Robert H. Morris, who prepared the heavy-mineral chart (fig. 17). Sandstone samples were disaggregated and treated with dilute hydrochloric acid to remove the carbonates. The disaggregate was sieved, and the material passing the 80-mesh and retained on the 235-mesh screen was separated in bromoform (sp gr 2.7) and methylene iodide (sp gr 3.0) into light, medium, and heavy fractions. Slides of the heavy fractions (sp gr 3.0 or greater) were prepared with canada balsam or aroclor. In Topagoruk test well 1 the glaucophane zone is represented by one sample at 304 feet, the prismatic-tourmaline zone by samples at 7,810 and 7,836 feet, and the rounded tourmaline zone by samples at 9,420 and 9,456 feet. Three additional samples, taken between 600 and 1,800 feet, were not assigned to any zone.

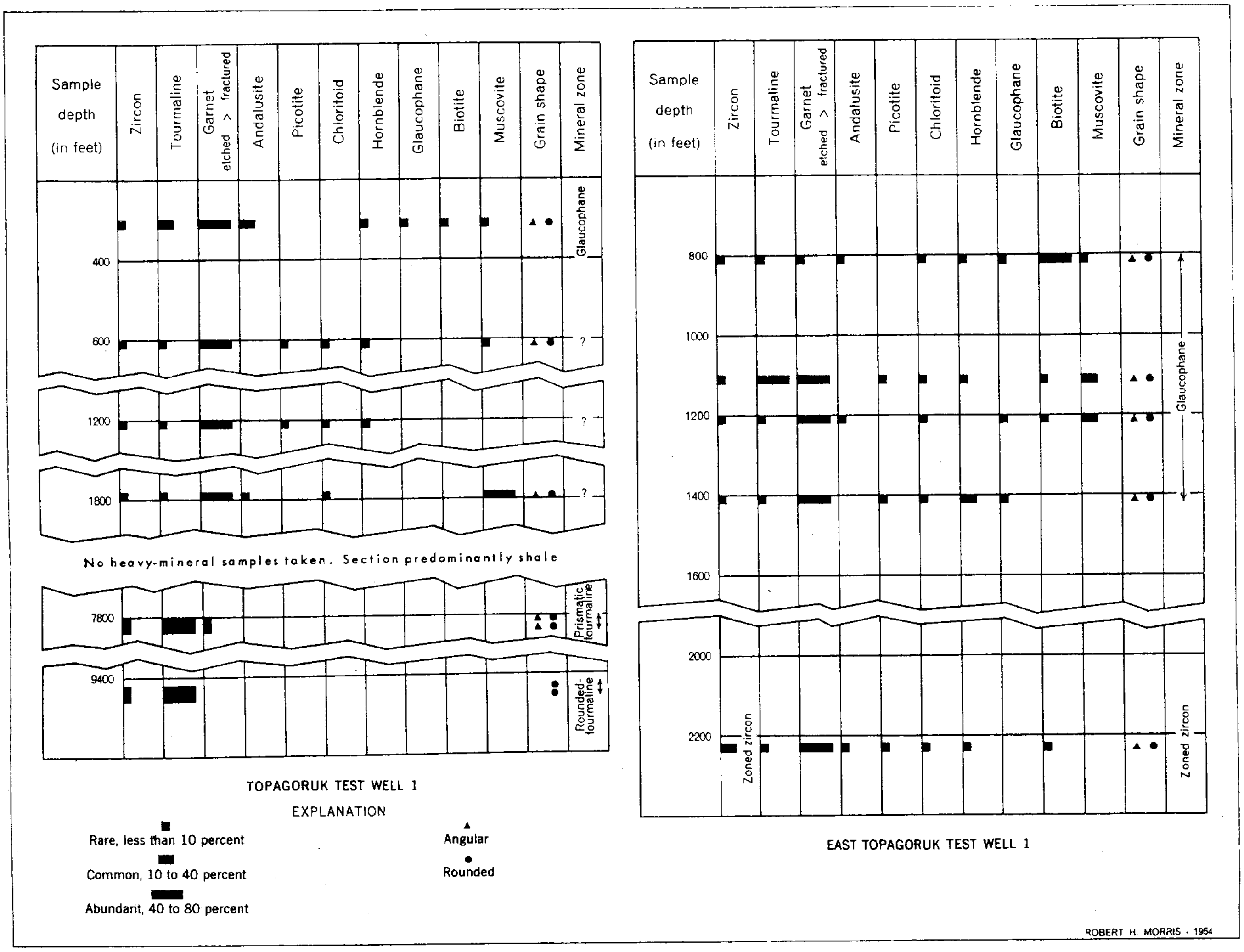

FIGURE 17.—Relative abundance of heavy minerals in Topagoruk test well 1 and East Topagoruk test well 1.

CORE ANALYSES

Effective porosity, air permeability, and carbonate-mineral content of core samples from Topagoruk test well 1 are shown in the following table. The porosity was determined by the Barnes method; the air permeabilities were determined on a permeameter, the general requirements for which are detailed in American Petroleum Institute Code No. 27, second edition, April 1942. Test plugs were cut parallel to bedding, unless otherwise specified. Specific gravity of core samples from the lower part of the well are shown on page 290.

Analyses of core samples from Topagoruk test well 1

Core	Depth (feet)	Effective porosity (percent)	Air permeability (millidarcys)	Carbonate content (percent by weight)
1	304P [1]	11.0	5.17	16.38
	304N [2]	11.1	0	

See footnotes at end of table.

Analyses of core samples from Topagoruk test well 1—Continued

Core	Depth (feet)	Effective porosity (percent)	Air permeability (millidarcys)	Carbonate content (percent by weight)
2	603P	26.2	316.2	
	603N	27.2	219.8	
4	1,204P	26.0	200.4	14.7
	1,204N	23.1	128.9	
	1,209P	21.3	169.1	13.2
	1,209N	16.6	108.8	
6	1,790–1,800P (1 ft from top)	18.1	11.8	16.4
	1,790–1,800P (1 ft from bottom)	17.7	0	
42	5,972P	10.0	0	2.2
51	6,141P	11.8	0	10.0
54	6,498P	4.72	0	16.5
64	7,835P	6.4	<1	
71	9,420P	6.9	0	16.2
	9,420N	6.61	0	
72	9,427P			51.2
73	9,435P			6.8
	9,450P			5.26
	9,453P			27.0

[1] Test plug made to determine permeability parallel to bedding.
[2] Test plug made to determine permeability perpendicular to bedding.

Specific gravity of some core samples from Topagoruk test well 1

Core	Depth (feet)	Lithology	Specific gravity
63	7,804–7,814	Argillaceous glauconite sandstone	3.35
64	7,829	Siltstone	2.64
64	7,834	do	2.57
65	7,842	do	2.46
65	8,104	Shale	2.66
68	8,629	Siltstone	2.59
69	8,917	Clay shale	2.01
70	9,202	do	2.69
73	9,441	Siliceous siltstone	2.68
77	9,504	do	2.62
79	9,540	do	2.67
82	9,817	Red siltstone	2.72
83	10,007–10,017	Red chert conglomerate	2.69
84	10,017–10,022	Red siltstone	2.68
86	10,228	Chert conglomerate	2.71
88	10,394	do	2.64
90	10,440	Claystone	2.68
95	10,476	Chert conglomerate	2.63

OIL AND GAS

OIL AND GAS SHOWS

Only a few slight shows of oil or gas were noted in this well by the Arctic Contractors personnel. The first found, a slight blow of gas from siltstone and sandstone at 5,959–5,988 feet, gave a maximum Baroid gas detector reading of 0.26 milliampere. A sample from 5,970 feet had a pale-yellow cut and yellow residue in carbon tetrachloride. (The rock was crushed, carbon tetrachloride was added, and the mixture shaken. Any color appearing in the carbon tetrachloride after settling and filtering was described as the cut; the residue is any material left in the evaporating dish after the liquid had evaporated.) Another sandstone, which fluoresced and had a gas odor and amber cut, was present at 6,140–6,144 feet.

Two samples from this sandstone were tested for fluid saturation in the Fairbanks laboratory, and one from 6,141 feet contained 4.81 percent of petroleum and 2.84 percent of basic sediment and water by volume; the other, from 6,143 feet, contained 3.08 percent of petroleum and 2.15 percent of basic sediment and water. A third sandstone, from 6,498 feet, had a yellow cut and residue in carbon tetrachloride.

FORMATION TESTS

Test 1, 5,960–6,052 feet.—The Johnston formation tester was set with an open-hole sidewall packer at 5,960 feet, with 91.72 feet of tailpipe and a 5/16-inch bean. It was open for 30 minutes, and a very slight blow was recorded, but there was no odor of oil or gas. The fluid level remained constant for the 30 minutes and then dropped very suddenly. The packer was pulled out of the hole, and 2,600 feet of mud was recovered. The pressure was zero during the test, but rose to 3,700 psi when the packer failed because of the hydrostatic head.

Test 2, 6,050–6,162 feet.—The Johnston formation tester with a casing packer was set in the 10¾-inch casing at 6,005 feet. A 5/16-inch bean and 27.40 feet of tailpipe were used. The tool was open 35 minutes; there was a moderate blow of air decreasing to a very slight blow at the end of the test. No oil was recovered; only 796 feet of drilling mud was recovered, of which 265 feet was cement contaminated. The salinity of the mud before the test was 60 grains per gallon, with a pH of 9.2; after the test the salinity of the mud recovered was 120 grains per gallon, and the pH was 11.0.

LOGISTICS

Supplies, equipment, and personnel were moved from the base camp at Barrow to the well site by tractor train and air. Prefabricated quonset and jamesway huts and wanigans, as well as heavy drilling equipment and supplies, were freighted overland during the winter, while planes, primarily C–47's, transported personnel and perishable or emergency supplies all year round. An airstrip big enough for such planes was constructed on a nearby gravel bar. A total of 4,700 tons of material was carried by the tractor trains, and 500 tons by air.

Personnel.—A petroleum engineer, a geologist, and a drilling foreman served as supervisors at the rig. The crew consisted of 2 drillers, 2 derrickmen, 6 floormen, 2 firemen, 2 heavy-duty mechanics, and 1 oiler. Besides the crew, there were 2 tractor operators, 2 cooks, a kitchen helper, a janitor, an electrician, and a man who acted as oil-field warehousekeeper, timekeeper and storekeeper.

Specialists in mud control, electric logging, diamond coring, cementing, and refrigeration, as well as carpenters, laborers, rig builders, and plumbers, were sent from the camp at Barrow when they were needed.

Housing.—The camp constructed at the well site consisted of 6 quonset huts, 1 jamesway hut, and 8 wanigans. (A jamesway hut is similar in shape to a quonset but is made of canvas over a metal frame and is usually slightly smaller. A wanigan is a small 1-room building which lacks a foundation; it may be mounted on skids or runners to facilitate moving.) Three of the quonsets were used for sleeping, and the others for galley-mess, warehouse, and recreation. The jamesway hut and some buildings that were part of the tractor train were also used for sleeping accommodations. The wanigans housed the engineering and geological office, power supply, generators, boiler, mechanic's workshop, the water supply, radio equipment, and lavatory.

Vehicles and heavy equipment.—Besides the tractors and airplanes that brought equipment, supplies, and personnel to the site, several other vehicles were used during drilling operations. These included 2 weasels (military fully tracked vehicles), an LVT (landing vehicle, tracked), a small TD–9 crane (cherry picker), D8 and D6 Caterpillar tractors, the latter with a crane attachment; and a swing crane. The drilling equipment used by Arctic Contractors is given below.

1..McClintic Marshall 150-ft steel derrick, type ODY, galvanized, with type YA frame window, 32-ft base, and 11-ft substructure.
1..Ideal drawworks, type 125, with catheads on both sides, and Parkersburg Hydromatic brake. The catheads are Foster Air Master Breakout cathead with air controls, and Foster air spinner cathead, also with air controls.
3..General Motors 6-cylinder quad, diesel engines, series 71, model 24103.
1..Byron-Jackson 300-ton hook, Super Triplex "4300."
1..Martin-Decker weight indicator and Drillogger, consisting of recording type "D" weight indicator, recording mud-pump gauge, recording rate of penetration, and recording and indicating rotary-table tachometer.
2..Ideal slush pumps, type C–350.
1..Ideal 300-ton traveling block, type 548–TC.
1..Ideal 360-ton crown-block type 648–TU, with a 15-in. catline sheave and an 18-in. sandline sheave.
1..Ideal 200-ton swivel, type RC–3.
1..Ideal rotary 20½-in. table, type SHS with table guard.
1..Ideal 300-ton connector, type DA–30.
2..Marlow mud pumps, model 445 HE, with 4-inch double diaphragm, and a 5-hp explosion-proof electric motor.
1..Cameron blowout preventer, type QRC, series 1500, 10-in. size, with 10,000 psi test and 5,000 psi working pressure.
1..Hydril blowout preventer, type GK, size 10, series 1500, with studded-face body, 10,000 psi test pressure and 5,000 psi working pressure.
1..Shaffer blowout preventer, type 34, series 900.
1..Hydril automatic accumulator unit for operating both Hydril and Cameron blowout preventors, model HB–17, with 90-gal reservoir tank.
3..Medearis mud suction tanks, with a capacity of 150 bbl. One tank with 2 Overstrom mud shakers, model MS 20–B, 54 by 60 in., each powered by 2-hp Wagner electric motors.
1..Halliburton cementing unit, type YP, with a Halliburton type AC pump.
1..Bulk-cement container, 200-sack capacity.
1..Kewanee 50-hp boiler, series 581.

Fuel, water, and lubricant consumption.—Diesel oil and 72-octane gasoline consumed as fuel totaled 463,862 gallons and 8,764 gallons, respectively; lubrication required 3,016 pounds of grease, 3,719 gallons of thread-lubricating compound, 2,943 gallons of no. 9170 lubricating oil, 2,687 gallons of no. 9500 oil, and 1,456 gallons of Delo. The amount of water used in drilling the hole was 3,743,000 gallons.

DRILLING OPERATIONS

RIG FOUNDATION

Information presented in this section was recorded by John C. Bollenbacher, C. S. Roberts, R. A. Brooks, and Leonard C. Dickey, petroleum engineers.

The foundation designed for the rig at Topagoruk test well 1 consisted of 12- by 12-inch timber sills set on ground scraped free of tundra vegetation. Refrigerating pipes were fastened along the bottom of the timbers, to counteract the seasonal thaw and heat from the rig. A 675-cubic-foot refrigeration unit was used to cool the diesel fuel circulated as refrigerant. Thermometers measured the temperature of the outgoing and incoming coolant, the circulating mud, the air temperature outside the righouse, and the points of pressure underneath the timbers. The refrigerated sills made a satisfactory base for the rig, the only settling being under the mud pits, caused by the heat of the mud and the lack of air space between the pits and the timbers. Jacking the pits up once corrrected the slight lowering. The timbers under the mud pump also settled slightly, but the bumper hose connections allowed for a small misalinement of pipe. Heaters installed on the blowout preventers deflected heat downward beneath the rotary table. Some settling from excessive thawing there, noticed after a year of drilling, was counteracted by installing additional supports with short piling into the permafrost a few feet away from the thawed area. No further deflection of the rotary table took place.

DRILLING NOTES

Other drilling activities are discussed below under the appropriate depth.

Notes from drill records

Depth (feet)	*Remarks*
107	Set 3 joints of 18⅝-in., 70-lb casing to 106.91 ft, and cemented it with 89 sacks of Cal-Seal. Top two joints (60 ft) were jacketed with 24-in. casing.
1,101	Set 36 joints (1,101.6 ft) of 13⅜-in., 54.5-lb casing at 1,101 ft, and cemented it to surface with 620 sacks of standard portland cement and 180 sacks of oil-well type D cement. Water mixed with cement set from surface to 800 ft contained 10 percent of sodium chloride; water mixed with cement set between 800 and 1,101 ft contained 4 percent of calcium chloride. Jacketed 18⅝ in. casing pumped dry and sealed while waiting for cement to set. Shaffer control valves installed, and well-head connection made. Casing tested with 700 psi for 15 min, with no loss of pressure.
1,142	Middle one of 3 drill collars failed, leaving one drill collar, tool joints, and bit in hole. Fish recovered on second attempt.
2,733	Depth of the hole was corrected from 2,729 to 2,733 feet.
2,950	The 4-in. kelly was replaced with a 6-in. kelly.
3,968	Depth corrected from 3,970 to 3,968 ft.
4,689	Sand bridge found at 1,660 ft, when going in hole to core. Hole reamed and sand bridge cleaned out.

Notes from drill records—Continued

Depth (feet)	*Remarks*
4,739	Tight spot found in the hole at 4,389 ft, while coming out of hole.
4,848	On running in the hole, bit was worked to bottom, with some reaming, through a tight spot at 4,580 ft.
4,866	Tight spot at 4,710 ft enlarged by working bit and reaming.
5,193	Drill pipe stuck in hole at 1,710 ft, and spent a week attempting to jar loose while lubricating with diesel oil, of which 787 gal. were used. Drill pipe cut at 1,469 ft, and recovered from that depth, but the lower part could not be jarred loose. At end of second week of work, top of fish was lowered to 1,557 ft by cutting off and pulling the upper 87 ft. After reaming and cleaning out hole to 5,053 ft, the rest of the fish, which had fallen to the bottom of hole, was finally recovered 20 days after becoming stuck.
5,268	Drill pipe stuck again at 5,251 ft but was worked loose.
5,587	Drill pipe stuck but was worked loose in 3 hr. Several teeth broken from bit, which Globe junk basket did not recover when it was run to bottom of hole.
5,589	Tight hole reamed for an hour, but after drilling to 5,621 ft, pipe stuck twice, and though it was worked loose, hole had to be reamed again, for an hour.
5,780	Drill pipe stuck 3 stands off bottom but was worked loose. Wire-line core barrel hit and drilled through a bridge 10 stands above bottom of hole, and another one 2 stands above bottom.
5,802	After taking a core at 5,800 to 5,802 ft, circulation was lost. Sixty gallons of viscous mud pumped to bottom of hole without regaining circulation; after 45 bbl of a 60-bbl mixture of mud containing 56 sacks of Aquagel and 32 sacks of Jelflake was pumped in, circulation was restored. Drill pipe was then worked through a tight spot and hole cleaned out to bottom.
5,860	Drill pipe worked through a tight spot which prevented electric logging equipment from reaching bottom of hole on first attempt. Second run successful.
5,955	Stuck pipe caused difficulty in reaming between 5,780 and 5,955 ft.
6,003	Depth measurement corrected from 6,000 to 6,003 ft.
6,023	Johnston formation tester stuck at 2,760 ft and was pulled without making test. Tight spots reamed with 12¼-in. bit 58, one of several bits used primarily for reaming or cleaning out hole.
6,100	Drill pipe stuck and could not be pulled out of hole past a key seat at 2,840 ft. Pipe twisted off at 1,252 ft, leaving 1,588 ft of drill pipe, collars, and bit. Two days later, the fish, which had fallen part way down the hole, was pulled up to 1,270 ft, but bumper sub pin worked out of drill collar box, and fish and fishing tools were left in hole. After feeling for fish unsuccessfully with drilling bit, top of it was located at 1,566 ft with an electric log. Fishing tools recovered, but original fish remained in hole with top at 4,497 ft. After pumping a 25-bbl mixture of lubricating and diesel oil down hole, fish was worked loose and pulled out. Ten days required to recover it. Caliper survey was run, but instrument would not go below 4,500 ft. Record between 1,100 and 4,500 ft showed several tight spots. After reaming tight spots with bit 66 and a Grant 12¼-in. reamer, set and cemented 10¾-in. 55.5-lb N-80 Hydril flush-joint casing at 6,073 ft, with 220 sacks of Olympic type-C construction cement. Hole closed in for 18 hrs under 900 psi pressure. Top of cement found at 5,036 ft. Twenty barrels of diesel oil and 20 bbl of brine made with 1,000 lb of salt were pumped through a circulating joint at 1,065 ft, into annulus between 13⅜-in. and 10¾-in. casing, followed by 50 sacks of type-C construction cement. After 18 hr top of cement found at 796 ft.
6,348	Drill pipe twisted off again because of failure of mandrel in bumper sub. Fish recovered at first attempt.
6,542	Circulation lost while drilling through shale, and was restored with a slurry of Aquagel, Fibertex, and sawdust.
6,545	Electric log between 6,040 and 6,544 ft showed a piece of metal at 6,280–6,313 ft. Caliper log and second electric log with short electrode spacing showed it to be bottom joint from 10¾-in. casing; it had become detached and slipped down hole, which had been enlarged enough by caving to permit it to drop down. Casing had not interfered with drilling up to that time.
6,940	Drill pipe had to be worked and mud circulated for 2½-hr to reach bottom, because of caving shale.
7,009	Caving shale again slowed drilling.
7,042	Four hours of reaming and working pipe were necessary to reach bottom with the bit, because of caving shale.
7,154	Drilling stopped for several hours by high winds, and once for about 2½ days while waiting for Aquagel. Fifty sacks of Olympic type-C construction cement was pumped into hole through drill pipe at 6,291 ft. After plug had set at 6,255 ft, whipstock was set at that depth. Attempt to sidetrack hole (because of casing at 6,280–6,313 ft) unsuccessful. After cleaning out soft cement, hole was plugged to 6,197 ft with 70 sacks of Olympic construction cement and drilled out to 6,208 ft to make seat for Eastman removable whipstock. Sidetracked hole drilled to 6,228 ft, and whipstock reset at that depth, but this attempt to sidetrack hole also unsuccessful. Hole plugged with 52 sacks of Permanente construction cement (mixed

Notes from drill records—Continued

Depth (feet)	*Remarks*
	with water containing 2 percent of calcium chloride), to 6,210 ft and drilled out to 6,215 ft. After third unsuccessful sidetracking attempt, hole was plugged to 6,175 ft with 100 sacks of Olympic construction cement, mixed with water containing 3 percent of calcium chloride and heated to 80°F. Old hole successfully sidetracked from 6,175 ft, and drilling continued in new hole, although tight spots in hole had to be cleaned out at 6,120–6,125 and 6,152–6,162 ft. Total of 55 days was spent sidetracking and redrilling, from 6,175 ft to original total depth of 7,154 ft.
Note	Operations below 6,175 ft all in the sidetracked hole.
6,875	Drill pipe again twisted off at 5,136 ft, leaving drill pipe, collars, and bit in hole, but were recovered in a day with bit undamaged.
7,241	Drill-collar pin twisted off, leaving 83 ft of drill pipe and bit in hole, with top at 7,156 ft. After hours of intermittent reaming and circulating mud, fish was recovered 4 days later. Caving shale and tight spots necessitated much cleaning out and reaming and made it difficult to get bit to bottom. Raising mud weight reduced caving but caused loss of circulation.
7,357	Cement (100 sacks of Permanente type-C construction cement) was pumped into hole through drill pipe at 6,540 ft in order to seal rocks which were taking up mud and permit mud weight to be increased. Spent a week cleaning out hole after cementing, removing cement-contaminated mud, and treating mud.
7,421	A hundred sacks of construction cement pumped in hole at 6,540 ft, plugging hole to 6,428 ft. After 50 sacks of Hi-Early cement were added, pressure could be held at 850 psi (instead of 500 psi as before), giving the equivalent of a column of mud weighing 95.3 lb per cu ft. Following 13 days were spent conditioning the mud, increasing its weight, and cleaning out shale bridges.
7,456	Caving shale caused much difficulty in drilling, and required much cleaning out.
7,629	Drill pipe stuck again when bit was at 7,520 ft when coming out of the hole but was worked loose in 3 hr. Shale continued to cave while hole was being cleaned out, but after Aquagel and Driscose were added to increase mud viscosity, condition of hole improved.
7,763	Between 7,761 and 7,763 ft drilling progressed very rapidly, and circulation lost immediately thereafter. Thick mud containing 24 sacks of Aquagel and 250 lb of Jelflake was pumped through drill pipe at 7,745 ft, with only partial returns of mud. Hole plugged back to 7,670 ft with 50 sacks of Olympic construction cement mixed with 30 cu ft of water heated to 80°F. Plug drilled out without losing circulation, and drilling resumed.
8,714	Mud was lost occasionally, while drilling from 8,330 to 8,714 ft.
Note	Depth corrected from 8,710 to 8,714 ft.
8,733	Circulation lost again between 8,726 and 8,737 ft, but regained with mud mixed from 38 sacks of Aquagel, 126 of Baroid, 75 of StrataSeal, 21 of sawdust, and 20 of Jelflake.
8,809	Hole took mud rapidly between 8,800 and 8,809 ft, but circulation regained when new mud was mixed. Used all mud materials on hand and suspended drilling 3 days while waiting for more Aquagel to complete mixing.
8,857	Walls of hole became mudded while waiting for Aquagel, and circulation was maintained between 8,009 and 8,857 ft, but large amounts of caving shale caused tight spots in hole and necessitated much cleaning out when attempting to get to bottom with a new bit.
8,862	Cones from bit 134 were locked on pieces of junk in bottom of hole.
8,916	Hole took 45 bbl of mud, and drilling stopped for about 2 days while awaiting new supply of Aquagel for mixing a partial tank of new mud.
9,150	Between 8,930 and 9,035 ft, drill pipe stuck several times, but was worked loose each time. Caving shale and loss of mud also slowed drilling.
9,270	Tight hole and caving shale caused pipe to stick several times and necessitated a large amount of cleaning out.
9,290	Drilling shut down 3 days to repair suction lines broken by settling of mud tanks.
9,336	Depth corrected from 9,324 to 9,336 ft. Original depths are used in lithologic description.
9,434	Diamond-core barrel stuck temporarily at 9,434 ft.
9,436	Rate of penetration increased suddenly, and 56 bbl of mud lost between 9,436 and 9,440 ft.
9,454	Depth to bottom of core 74 corrected from 9,458 to 9,454 ft.
9,574	After about 2 days of circulating mud and waiting for a junkcatcher, catcher was run in hole and recovered fragments of drill-bit teeth.
9,770	Rate of penetration increased from 25 min per ft to 13 min per ft.
10,051	Cones came off rock bit. Next bit milled on them for 4 hr and was badly worn as a result of locked cones. When microlog equipment was run in hole, it stuck in tight spot at about 8,600 ft and was left in hole. The 18-ft fish recovered after short wait for fishing tools. After milling for 2 hr with a junk sub on a rock bit, numerous fragments of cones were recovered.
10,374	Depth corrected from 10,372 to 10,374 ft.
10,462	Missing gauge teeth from rock bit recovered with junk sub on another bit.
10,468	Drill pipe stuck for an hour at 9,280 ft.
10,472	Drilling suspended for 7 days while waiting for more diamond core bits.
10,503	Depth corrected from 10,506 ft. A 6-ft by 10¾-in. riser installed on top of 10¾-in. casing with a coupling. It extended 3 ft above surface of ground.

DRILL AND CORE BITS

A total of 227 drill bits were used on Topagoruk test well 1, beside a few unnumbered bits such as a Globe basket, Eastman rock bit, or a wire line core barrel and bit that deepened the hole a foot or two while cleaning it out. Over 50 Hughes W7R drill bits were used, and lesser numbers of other Hughes, Reed, and Security bits, ranging in size from 20½ to 9⅝ inches. Many of them (Nos. 65, 66, 80, 95, 97, 98, 101, 214, and 223), of various makes, were used entirely for reaming or cleaning out and consequently are not shown on the graphic log (pl. 17). Because they were used only to circulate mud, bits 226 and 227 were also omitted. Bit 7 acted as a pilot bit for bits 8 and 8a, bit 78 cleaned out cement, and bits 132 and 186 milled on junk. The Eastman 7½-inch rock bit mentioned above and a Reed 7⅝-inch bit ground down to 7½ inches were used to start the sidetracked hole, drilling from 6,175 to 6,221 feet. Many of the bits used in drilling also did a large amount of cleaning out and reaming, especially between 4,200 and 9,500 feet.

Except for 3 Security bits, all the 834 feet of coring was done by Reed conventional and wire line bits and by Christiansen diamond core bits. The former were 7⅝ to 12¼ inches in diameter, the latter, 9⅝ inches across. Two of the Reed wire line bits did not take any cores; one, number 24, cored only cement and did some reaming, whereas the other, number 25, did not take a core because of the poor condition of the hole.

The diamond core bits were used primarily to reduce drilling time per foot penetrated between 9,433 and 9,597 feet and from 10,384 to 10,503 feet; the rock consisted primarily of chert conglomerate and of hard sandstone and shale. Because of the sidetracked hole at 6,175 feet, the length of the Christiansen core barrel was limited to 30 feet. Two types of face-discharge diamond bits were used: model C–18–B was coarse-set with large bortz; the other, model B–18–B, had closely set fine bortz. The latter had a better rate of penetration, and 8 of the 10 bits were of this type. The rock recovered was 95.7 percent of that cored, although nearly vertical fractures occasionally caused difficulty by blocking the core barrel when drilling the sandstone and shale; pebbles from the chert conglomerate seemed to have a similar effect. Weight on the bit during coring varied from 8,000 to 25,000 pounds, rotary speed ranged from 30 to 70 revolutions per minute, and pump pressures, from 800 to 1,100 pounds per square inch, depending on the type of rock being drilled.

DRILLING MUD

The drilling mud used in the upper part of Topagoruk test well 1 was a clay and water mixture which was discarded after setting the surface casing, because of cement contamination. Subsequently, the mud was treated with Aquagel to maintain proper colloidal properties, and quebracho and tetrasodium pyrophosphate to regulate fluid loss, viscosity, and wall-building properties. When the hole was a little deeper than 3,000 feet, mud weight increased from 70 to 90 pounds per cubic foot; the temperature rose from 46° to 85°F; the viscosity remained at 40 Marsh funnel seconds; and the water loss decreased from 15 to 3.5 cubic centimeters per minute. Although viscosity increased to 55 Marsh funnel seconds just above 5,800 feet, circulation was lost at that depth and again at 6,003 feet; it was restored the first time by pumping in a very viscous Jelflake mixture and the second time after adding Aquagel. It was lost a third time at 6,542 feet, and regained after losing 206 barrels of fluid containing Aquagel, Fibertex, and sawdust; the mud weight was reduced to 70 pounds per cubic foot to prevent further loss. Plugging before sidetracking at 6,174 feet contaminated the mud with cement, and it was treated with sodium bicarbonate and quebracho. Below 6,200 feet shale frequently caved into the hole, and a large amount of Baroid was added to increase the mud weight and thus furnish more support to the walls of the hole. This increased the water loss; so, the weight was reduced from 88 to 80 pounds per cubic foot, and Driscose was added to maintain low water loss. Contamination from the cement plugs continued to alter the desired mud characteristics, requiring the addition of more quebracho and acid pyrophosphate after cementing a zone at 6,542 feet to reduce loss of circulation and caving shale. Very large amounts of Baroid were again added to reduce sloughing by increasing mud weight to 90 pounds per cubic foot, and the viscosity was increased to 120–140 Marsh funnel seconds in attempting to remove a large quantity of caving shale from the hole. During and after cementing the hole again at 7,750 feet, tetrasodium pyrophosphate and Driscose were added to reduce circulation loss.

Caving and lost circulation delayed drilling and required the excessive use of additives, which were expensive and difficult to keep in supply and transport to the well site. An expert on mud advised converting the fluid to a 15-percent oil-emulsion mud, which was done by adding crude oil from core tests near Cape Simpson to the system. Quebracho was added to control water loss, and caustic soda, to aid in keeping the oil in emulsion by increasing the alkalinity; the caustic also increased the gel strength and gel rate. Sodium bicarbonate was added each day to reduce the calcium-ion concentration of the mud and to increase dispersion. These changes improved the mud characteristics, and caving ceased to be a serious problem.

The following table shows the characteristics of the mud and the materials added during drilling. The lists of additives have been compiled from several reports, and as there were a few discrepancies in the records, the following totals are approximate: 12,700 100-pound sacks of Baroid and 3,800 100-pound sacks of Aquagel, nearly 20,000 pounds of quebracho, 8,300 pounds of tetrasodium pyrophosphate, 5,500 pounds of acid pyrophosphate, 4,000 pounds of Driscose, 3,550 pounds of sodium bicarbonate, 2,140 pounds of caustic soda, and 250 barrels of crude oil. Minor amounts of other materials—Fibertex, sawdust, Jelflake, and others—also were used.

At several points in the hole where fishing, mixing new mud, or other operations slowed the drilling, an unusually large amount of additives were used at a single depth.

Drilling-mud characteristics and additives, Topagoruk test well 1

Depth (feet)	Weight (lb per cu ft)	Viscosity (Marsh funnel sec)	Water loss (cc per 30 min)	Temperature (°F)	Aquagel (100-lb sacks)	Quebracho (lb)	Baroid (100-lb sacks)	Tetrasodium pyrophosphate (lb)	Acid pyrophosphate (lb)	Sodium bicarbonate (lb)	Caustic soda (lb)	Crude oil (bbl)	Driscose (lb)	Other additives
57					20									
111					25									
312	70.0	38		45	25									
595	76.0	38		46										
765	75.0	37		50										
921	77.0	37		50	28									
1,074	80.0	40	18.0	52		65		55						
1,100	80.0	40	15.0	54										
1,106					120									
1,145	69.0	38	18.0	51										
1,222	71.0	39	14.0	52										
1,364						10		10						
1,467	72.0	40	15.0	59										
1,604	71.0	38	13.0	67										
1,800	74.0	40	12.0	68										
2,086	76.0	37	9.0	65										
2,200	78.0	42	9.0	72		10		10						
2,282	80.0	38	6.0	74										
2,342					6									
2,390	82.0	39	6.0	74										
2,452	84.0	42	5.5	76										
2,525	85.0	43	4.5	76		25		25						
2,630	86.0	40	3.0	81		30		30						
2,692	86.5	41	3.0	76										
2,729						10		10						
2,760	87.0	43	3.0	74	9									
2,800					72	10		10						
2,828	86.0	43	3.5	82										
2,921	87.0	42	3.5	83		5		5						
2,950	87.0	43	3.5	87										
3,016	87.0	42	3.0	80										
3,086	87.0	42	3.0	75										
3,165	87.0	42	3.0	83										
3,257	88.0	43	2.5	80			20							
3,413	89.0	42	3.0	86		10								
3,533	89.0	43	3.0	91										
3,566	85.0	38	3.0	84										
3,621	87.0	38	3.5	90										
3,764	88.0	39	3.0	89										
3,806	87.0	39	3.0	85										
3,890	87.0	39	3.5	78			4							
3.935	86.0	39	3.0	73										
4,009	86.0	38	4.0	80			3							
4,069	86.0	39	4.0	84			6							
4,110	86.0	40	4.0	82			12							
4,175	87.0	41	3.5	80			2							
4,200	88.0	40	3.5	80										
4,240							5							
4,307	88.0	40	4.0	82			13							
4,348	88.0	41	4.0	82			8							
4,418	87.0	38	4.0	83										
4,478	88.0	39	4.5	86										
4,544	86.0	38	4.5	86	8		8							
4,585	87.0	40	4.0	82										
4,635	88.0	39	4.5	84			14							
4,669	87.0	40	5.0	82			7							
4,685	88.0	40	5.0	80										
4,689	89.0	43	3.5	84	20	20		20						
4,692						35		20						

Drilling-mud characteristics and additives, Topagoruk test well 1—Continued

Depth (feet)	Weight (lb per cu ft)	Viscosity (Marsh funnel sec)	Water loss (cc per 30 min)	Temperature (°F)	Aquagel (100-lb sacks)	Quebracho (lb)	Baroid (100-lb sacks)	Tetrasodium pyrophosphate (lb)	Acid pyrophosphate (lb)	Sodium bicarbonate (lb)	Caustic soda (lb)	Crude oil (bbl)	Driscose (lb)	Other additives
4,721						20		15						
4,739	91.0	44	3.0	85		10		10						
4,749						15	10	5						
4,770	91.5	45	3.0	85		10		10						
4,790	91.0	45	3.5	80		10		10						
4,828	91.0	43	3.5	81										
4,843	91.0	44	3.5	84	12	10	10	10						
4,866					6		10							
4,885	91.0	45	3.5	86		30		30						
4,895	91.0	44	3.5	84										
4,916	91.0	43	3.5	82		35	10	45						
4,987	91.0	44	3.0	85	18	20	10	45						
5,016	91.0	45	3.0	86		15	13	20						
5,091	90.5	44	3.5	85	15	20	9	10						
5,139	90.0	44	3.5	83	10		10							
5,193	88.0	47	3.0	81	83		357							
5,268	90.0	68	3.0	76	28		213							
5,288	89.0	78	3.0	73			30							
5,329	90.0	66	3.0	72				90						
5,360	89.0	73	3.0	72										
5,375	90.0	60	3.0	72				300						
5,460	89.5	56	3.0	84				50						
5,480	89.0	55	3.0	72			10							
5,572	89.0	64	3.5	80			30	50						
5,587	90.0	60	3.5	85			40	100						
5,589							47		75					
5,621	89.0	52	3.5	82		10		20						
5,681	90.0	51	3.5	87		100		50						
5,731	90.0	54	3.5	91		100								
5,755					16			25						
5,780	89.5	50	3.5	86										
5,800	89.0	54	3.5	78		105		15						
5,802					56									32 sacks Jelflake.
5,854	87.5	51	3.0	74	46	100	35							
5,865	87.0	65	3.0	78										
5,918	87.0	55	3.0	80										
5,954	87.0	56	3.0	86			10							
5,987	87.0	56	3.0	84										
6,000	87.0	56	2.5	84			15	50						
6,008	87.0	59	3.0	79	49	200								
6,023	87.0	61	2.5	83			10							
6,033	87.0	62	3.0	80		100								
6,052	85.0	62	3.0	81										
6,100	87.5	64	3.0	83	45	650	165	200		400		20	200	
6,127	79.0	56	4.0	80		100								
6,160														100 lb Stabilite-8.
6,238	80.5	46	5.0	80										
6,348	82.0	45	5.0	87		150	13							
6,368	82.0	47	5.0	80										
6,480	84.0	48	4.0	92		100								
6,510	85.5	50	3.5	82										
6,542	86.0	46	3.5	84	87									12 sacks sawdust, 9 sacks Fibertex.
6,545	80.0	46	3.5	88	15									13 sacks Fibertex, 12 sacks sawdust.
6,627	79.5	54	3.5	84										
6,743	79.0	51	3.5	90										
6,753	79.0	50	3.5	93										
6,850	78.5	54	4.0	90	23		30							
6,907	79.0	55	3.5	92										
6,950	79.0	58	3.5	96										
7,009	81.0	57	3.5	100	10									
7,042	81.5	63	3.5	102	15		45	100						
7,062	80.5	66	3.5	96	5		10							
7,141	81.5	65	3.0	98										
7,154	81.5	65	3.0	98	173	580	612	505		1,050				
6,175 [1]	78.0	43	4.0	76									150	
6,190	78.5	43	3.9	79										
6,200	78.0	46	4.0	78										
6,221	78.5	43	4.6	74		180	17						150	
6,250	78.0	40	4.6	74	35	65	5							
6,275	78.0	48	3.6	74	12	40								

Drilling-mud characteristics and additives, Topagoruk test well 1—Continued

Depth (feet)	Weight (lb per cu ft)	Viscosity (Marsh funnel sec)	Water loss (cc per 30 min)	Temperature (°F)	Aquagel (100-lb sacks)	Quebracho (lb)	Baroid (100-lb sacks)	Tetrasodium pyrophosphate (lb)	Acid pyrophosphate (lb)	Sodium bicarbonate (lb)	Caustic soda (lb)	Crude oil (bbl)	Driscose (lb)	Other additives
6,308					12	25								
6,340	80.0	53	3.5	92										
6,365							6							
6,452	80.0	53	3.6	94										
6,522						100								
6,530	80.0	54	3.7	98										
6,591						60	5							
6,618	80.5	56	3.7	97										
6,708	81.0	57	3.4	97		75							100	
6,738							8							
6,800	81.5	49	3.2	95		100								
6,836						25	6							
6,875	80.5	47	3.4	92										
6,927	82.0	48	3.5	88										
6,995						65								
7,055	82.0	48	3.4	92		75								
7,109						60								
7,154	83.0	47	3.2											
7,200	83.0	47	3.0	104										
7,241	83.0	47	3.0	104	51	425	203	60					50	
7,255						50								
7,292	85.5	64	3.0	101	21		70							
7,295					10	130	11						100	
7,333	82.0	64	3.5	98										
7,357	82.5	60	3.5	99	347	1,200	55	595	550				50	
7,407	76.0	72	3.0	100		100								
7,415	77.0	66	3.5	100										
7,421	77.0	70	3.5	105	246	1,250	1,173	225	250				550	
7,435	80.5	64	2.0	114										
7,440							15							
7,456	80.0	85	2.5	104										
7,484							102							
7,496	81.0	87	2.5	102		200	291	400	200					
7,515	84.0	79	2.0	96			48							
7,554							165							
7,564	85.0	79	2.5	100	27		335	325					100	
7,613	85.0	115	2.5	96									100	
7,629		105	2.0	102	47		42						100	
7,686	90.0	127	2.0	110				100	80					
7,701							21							
7,758	89.5	130	2.0	104									100	
7,763	89.0	120	2.0	100	535	300	1,650	1,400	200					35 sacks sawdust, 26 sacks Jelflake.
7,804	86.0	90	3.5	78	197	175	1,052	100	150				100	33 sacks sawdust, 6 sacks Jelflake.
7,834					23	200	120	200						
7,857	82.0	75	3.5	96		50	150		50					
7,858						400		350						200 lb Stabilite-8.
7,878						50		50		100				Do.
7,898	82.5	72	4.0	100	21	100	75		200	200				
7,921						150	30	200					100	
7,971	83.0	80	3.5	102										
8,002					25	50	30	50						
8,069	84.0	94	3.5	104	25	100							100	
8,104						150	15			150			50	
8,109	84.0	115	3.5	100		50	106		50					
8,114						50	51	50					100	
8,159	85.5	100	3.0	104									100	
8,197	84.5	105	3.5	106			25	100						
8,262					25		198		400					
8,337	85.0	70	3.5	104	14	100	273							
8,410	87.5	87	3.0	104	44									
8,416	86.0	90	3.0	100	49	100								
8,443					25				50					
8,455	85.0	125	3.0	105		100	21							
8,508	84.0	155	2.5	112	50									
8,513						75								
8,530	84.0	185	2.0	110		200								
8,572	83.5	185	3.0	113		150	36							
8,592							90	50						
8,596	83.5	137	3.5	95					150					
8,609							24	150						

Drilling-mud characteristics and additives, Topagoruk test well 1—Continued

Depth (feet)	Weight (lb per cu ft)	Viscosity (Marsh funnel sec)	Water loss (cc per 30 min)	Temperature (°F)	Aquagel (100-lb sacks)	Quebracho (lb)	Baroid (100-lb sacks)	Tetrasodium pyrophosphate (lb)	Acid pyrophosphate (lb)	Sodium bicarbonate (lb)	Caustic soda (lb)	Crude oil (bbl)	Driscose (lb)	Other additives
8,617	84.0	118	3.5	100			33							
8,625							15	50						
8,629	85.0	125	3.0	102		50	88		100				100	
8,634	84.5	146	3.0	98				50						
8,643							18							
8,674	85.0	136	3.0	116										145 sacks Strataseal.
8,684	85.5	140	3.5	100		100		100						
8,686							69	50						
8,695	86.0	150	3.0	116										
8,708									75					
8,710	86.0	100	3.0	99			33		50					
8,717									100					
8,719	86.5	112	3.5	110	25				100					
8,721	86.0	145	2.5	102	25									
8,725					13		123							
8,730	85.5	120	2.5	104	94		375							
8,737	83.0	135	3.5	92	38		153							75 sacks Strataseal, 20 sacks Jelflake, 21 sacks sawdust.
8,772	82.5	170		100										
8,776					26		11							50 sacks Strataseal.
8,800	84.0	90		92			88		150					
8,809	84.0	90		108	20		175		250					
8,822					42		227							
8,838	83.5	126		106	4		28							
8,840									200					
8,841	83.0	130		111		25								
8,847	83.0	100		114										
8,853					86	200	174	100	350					
8,856	84.0	115		112			100		150					
8,859	86.0	110		116	53		136		200					
8,860		155	3.5	116			25		75					50 sacks Strataseal.
8,862	86.0	150		100					200					15 sacks Strataseal.
8,878	86.0	160	3.5	100	15		25	50	100					14 sacks Strataseal.
8,899	87.0	165	3.0	104			25		50					
8,901					15									
8,917				90	46	250	207	25						10 sacks Fibertex.
8,921						50	21							
8,930	85.0	118	3.0	98	14		48							
8,940						100								
8,946	86.0	126	3.0	103		50		25						
8,972	86.0	180	3.0	103		50	24	50						
8,995		150	3.5	110		50	48							
9,010	86.0	150	3.5	104										
9,017						75								
9,035	85.0	185	4.0	90	30	375	153	175						
9,056					375	50	111							
9,066	86.0	102	5.0	103				100						16 lb Stabilite-8.
9,080	86.0	95	3.0	103				50						15 lb Stabilite-8.
9,102	86.0	105	3.5	112				200						
9,110						500							150	
9,120	85.5	96	3.5	108			21		25					
9,131							21	150					3	
9,148	85.5	98	3.5	110										
9,162								100					100	
9,178	86.0	95	3.5	110		125	21	25						
9,183	86.0	98	3.0	103	17	1000								
9,199	86.5	105	2.5	115				100					50	
9,202						150		150						
9,221					20	200	129	200						
9,225	87.0	72	3.0	109										
9,243						100							200	
9,248	87.0	87	2.5	110		50		25						
9,261					25	200								
9,270	86.5	91	3.0	110		50		25						
9,283						200								
9,290	85.5	94	3.0	108		50								25 lb Stabilite-8.
9,308	86.0	125	3.5	110	16		112							
9,318	86.5	100	3.5	108								50		
9,324												50		
9,340	84.0	136	2.0	110										
9,357	85.0	139	4.5	108			24			100				

Drilling-mud characteristics and additives, Topagoruk test well 1—Continued

Depth (feet)	Weight (lb per cu ft)	Viscosity (Marsh funnel sec)	Water loss (cc per 30 min)	Temperature (°F)	Aquagel (100-lb sacks)	Quebracho (lb)	Baroid (100-lb sacks)	Tetrasodium pyrophosphate (lb)	Acid pyrophosphate (lb)	Sodium bicarbonate (lb)	Caustic soda (lb)	Crude oil (bbl)	Driscose (lb)	Other additives
9,374	84.5	107	4.5	114			12			200				
9,385	84.5	109	5.5	120	12	50	24				10			
9,396	84.5	130	4.5	110	12	75					15		100	
9,405	84.0	174	4.5	115		25				200	15			
9,416	83.5	144	4.5	110		50	12					50		
9,432	83.0	120	4.0	118		50				100	10		200	
9,433						150	12			50	15			
9,437	83.0	147	4.5	110										
9,455	84.0	140	3.5	112	12	250	48			75	40			
9,457	83.5	122	4.0	116		75				25	15			
9,459		135				50	12				10			
9,462	83.0	144	4.5	113	6	50	81				10	5		
9,474	83.5	150	4.5	116		100	12			100	10	5		
9,496	83.5	148	3.5	116		50					10			
9,523	83.5	137	4.0	116		50				50	5			
9,538	83.0	138	4.0	117		100	12				5			
9,544	83.0	146	4.5	118		50					5			
9,557	83.5	149	4.0	117		25				25	5			
9,568	84.0	160	4.0	116	12	50	135			25	10	9		
9,574	83.5	166	4.5	118		200	12				10			
9,597	83.5	134	4.5	120						50			100	
9,616	84.5	162	4.0	117		50				25	10			
9,648	84.5	185	4.0	120	15	25	145			25	5			
9,681	84.0	170	5.0	118		75				15	5			
9,705	83.5	189	4.5	120		250				15	5		150	
9,727	83.5	181	4.0	120		100	12					20		
9,762	83.5	136	4.5	118		150	12							
9,791	83.5	122	5.0	120		100	12							
9,800	83.0	115	5.5	118		50	12			50				
9,816	83.0	125	4.5	117		50					10			
9,828	83.5	130	5.0	118		25	12			25	5			
9,858	83.5	134	4.5	118	24	50	12			50	15	20		
9,903	83.5	140	4.0	114		75	12			15	15			
9,924	83.5	130	4.0	118		50	12			25	10			
9,952	83.0	105	4.0	120		25					5			
9,983	83.0	105	4.5	120		50				50	10			
10,012	83.5	125	4.5	118		50	12				10			
10,037	83.0	135	4.5	120		50	12				10			
10,051	84.0	125	5.0	122		50	42			15	10			
10,063	83.0	125	4.5	118		50	24				10			
10,084	83.5	115	5.0	118		25	12				5			
10,106	84.0	120	4.5	120	12	75	12				15			
10,123	84.0	105	5.0	115	10	25	12				10			
10,147	84.0	137	5.0	120		25	24							
10,159	83.5	140	4.5	118		50	12			50	10	20		
10,170	84.0	145	5.0	120		50	12				5			
10,208	84.5	160	5.0	122		50	6			20	10			
10,229	84.0	155	5.5	122		50	21			5	10			
10,261	84.0	133	5.5	120		75				10	5			
10,285	83.5	140	5.5	120	4	100	6				20			
10,302	84.0	160	5.5	120	6	50	6			20	15	20		
10,311	84.0	130	5.5	117	6	75	15			70	30			
10,321	83.5	156	5.0	118		75	12				35			
10,330	83.0	150	6.0			75	15			10				
10,343	83.0	157	5.0	114	6	50				10	20		100	
10,347		150	5.5	118		100	9			10	25			
10,351	84.0	150	5.5	118		60	6			10	10			
10,360	83.0	133	5.5	121		75	9			10	15		100	
10,363		114		110	6	25	32				5		100	
10,365	83.0	110	4.5	107		25	12							
10,370	83.0	140	5.5	114	10	75	12			10	15			
10,372	83.5	120	4.0	124		150	12			10	45			
10,377	83.0	122	5.5	125	20	125	9			10	75			
10,379	84.0	125	4.5	113		500	33			15	400			
10,382		120		116			18							
10,384						75	9				60			
10,385	84	130	5.0	120		100	9			10	80			
10,390	84.5	125	4.0	116		75	9				60			
10,403	84.5	128	3.5	119		75	12				60			
10,412	85.0	132	4.0	118		50	12				40			
10,433						50	12				40			
10,437	84.5	130	4.0	121										

Drilling-mud characteristics and additives, Topagoruk test well 1—Continued

Depth (feet)	Weight (lb per cu ft)	Viscosity (Marsh funnel sec)	Water loss (cc per 30 min)	Temperature (°F)	Aquagel (100-lb sacks)	Quebracho (lb)	Baroid (100-lb sacks)	Tetrasodium pyrophosphate (lb)	Acid pyrophosphate (lb)	Sodium bicarbonate (lb)	Caustic soda (lb)	Crude oil (bbl)	Driscose (lb)	Other additives
10,450	84.0	169	4.5	121		75	12				45			
10,460	83.5	180	4.0	120		125	24				100			
10,462	83.0	190	3.5	116	17	100	172				80			
10,464	84.5	190		110		50	12				30			
10,469	83.5	155	4.0	114		25	12			20	10			
10,472	84.0	135	4.5	118	32	450	36			40	200			
10,476	83.0	170	4.0	112		75	12				30			
10,479	84.5	160		115		100	12				60			
10,486	85.0	180		118		50	12				40			
10,490	85.0	160	4.0	116										
10,498	84.0	124	4.0	118		100					60			
10,501					15		12							
10,503	83.0	140	3.0	117		100	36				50			

[1] Between 6,175 and 7,154 ft, depths are duplicated because of the sidetracked hole.

HOLE DEVIATION

The upper part of the hole, above the sidetracked hole, was nearly vertical, with a deviation of less than 1° except at 2,800 feet, where it was 1°10′. The sidetracked hole had a deviation of 4° near its top, but the hole became straighter with depth, the deviation decreasing to zero at 8,000 feet. At 9,523 feet the hole was 3°40′ off vertical and averaged less than 2° from there to the total depth. The last reading, at the bottom of the hole, was 4°45′, the highest deviation recorded in the hole. The deviation measurements were made with a Totco (Technical Oil Tool Corp., Ltd.) recorder.

ELECTRIC LOGGING AND OTHER SURVEYS

Thirteen electric-log runs were made, the first with Widco instruments and the rest with Schlumberger equipment. The depths between which they were run are shown in the following table; part or all of some runs were overlapped by others; and consequently, on the graphic log (pl. 17), where a composite log for the well is shown, the overlapping runs have been omitted. Several of the runs have a lateral as well as long- and short-normal curves in the resistivity column, and the lateral curves have also been omitted, to avoid confusion.

Electric-log runs, Topagoruk test well 1

Run	*Depth (feet)*	*Run*	*Depth (feet)*
1	106–1,092	8a	6,000–6,330
2	1,105–3,056	9	6,200–7,748
3	3,000–4,796	10	7,660–8,213
4	4,750–5,681	11	8,200–8,715
5, 6	5,646–5,998	12	7,690–9,788
7	5,930–6,090	13	9,750–10,498
8	6,040–6,543		

Runs 5 and 6 were combined without recording the boundary between them. Run 7 is short, having been made to show the bottom part of the hole before setting casing. Run 8 was the first to show the parted casing (see p. 292) in the part of the hole later sidetracked (another short run was made to locate the casing more accurately). Run 8 is not shown on the graphic log (pl. 17), having been overlapped by other runs. Run 8a covered most of the same depth in the sidetracked hole. The casing in the old hole did not affect the long normal curve of run 9 at all, and the short normal curve only slightly. Runs 10 and 11 were completely overlapped by runs 9 and 12, in which the scale was changed at 9,000 feet in order to give a better picture of the interval of high resistivity below 9,000 feet.

A gamma-ray log was run from the surface to 6,900 feet, but it has not been shown on plate 17 because the depth logged is portrayed equally well by the electric log.

A hole-section survey was made between 1,105 and 4,493 feet. The hole was 6,100 feet deep when the survey was made, but a bridge at 4,493 feet prevented the instrument from going deeper. The survey showed the hole to be considerably larger than the bit sizes, except for a few tight places. A second survey from 5,970 to 6,320 feet showed the parted casing (at 6,280–6,313 feet) which was later sidetracked.

After setting casing two short temperature surveys were made with the Schlumberger equipment in order to locate the top of the cement.

A microlog, the first recorded in the Reserve, was run between 1,105 and 6,083 feet and showed sandstones at 1,800 and 2,600 feet to be permeable, and that at 3,315 to be less so. Sandstones at 5,540 and 5,970 feet are impermeable, although the lower sandstone may be fractured enough to be a possible reservoir.

VELOCITY SURVEY

A survey of seismic velocity was made by United Geophysical Co., Inc.; the results are as follows:

1. The average velocity increases steadily from 8,867 feet per second near the surface to 11,161 feet per second at the total depth.
2. Velocities of certain intervals range from 8,500 to 21,000 feet per second, with the 3 intervals of high velocities (about 20,000 feet per second) being below 9,000 feet in the hole.
3. The velocity at depth equals 8,520 feet per second plus 0.54 times the depth.
4. Seismic horizons were identified in the well at about 1,400, 7,000, 8,700, and 10,200 feet.

TEMPERATURE-MEASUREMENT STUDIES, TOPAGORUK TEST WELL 1

By MAX C. BREWER

Topagoruk test well 1, a deep rotary-drilled hole, is near the mouth of the Topagoruk River in an area characterized by many streams, lakes, and brackish lagoons (see fig. 15). The well site is about a quarter of a mile from a main channel of the river and about 100 yards from a small shallow lake.

Five heavy-duty thermal cables containing a total of 90 thermistors were installed in the hole on September 28, 1951, after drilling was completed. The maximum depth reached by the cables was 5,800 feet. An attempt was made to install a sixth cable with thermistors at depths between 5,800 feet and 10,500 feet, but the heavy drilling mud used in the hole prevented installing this cable at a depth greater than about 2,500 feet.

The 5,800-foot cable was short circuited by infiltration of fluids before any usable readings could be obtained and later parted baceause it was too weak to support its own weight. Reliable readings were obtained only to a depth of 1,340 feet. Daily temperature measurements were made at Topagoruk for 3 weeks following installation of the cables. At the end of that time, the well was still unfrozen throughout its entire length, with the minimum temperature near +2°C.

When the well was revisited on January 30, 1952, the lowest temperatures recorded, other than those near the surface, ranged from −3°C to −3.5°C at depths between 70 and 150 feet. The maximum depth of refreezing, if it is assumed that refreezing occurred at 0°C, was approximately 475 feet at this time. The assumption that refreezing occurs at 0°C does not take into account the depression of the freezing point caused by pressure, particle size, or chemical contamination of the water in the drilling mud. The use of this assumption is convenient in a discussion of permafrost and seldom results in significant error.

Temperatures were again measured on April 11, 1952, March 12, 1953, and June 7, 1955 and the 0°C isotherm had reached the approximate depths of 840, 880, and 990 feet by these respective dates.

The geothermal profiles to June 1955 were irregular, which is quite understandable when it is realized that drilling took 14½ months and that a return mud temperature of 49°C was reported, resulting in much heat transfer to the rock. In addition, the changes in lithologic character and in thermal diffusivity of the sediments would allow large differences in the amount of heat absorbed at different depths.

Arthur H. Lachenbruch (written communication, 1956) has calculated the approximate time necessary for the temperature at 1,200 feet in this hole to return to within various degrees of the original equilibrium temperature. The results of these calculations are shown in the following table.

Approximate time for return to thermal equilibrium at the 1,200-foot depth in Topagoruk test well 1

Required time (in years after drilling ceased)	Departure from equilibrium (°C)
1¾	5
2¾	2.75
5	1.33
6¼	1
55	.1
500–600	.01
∞	Equilibrium

The projected equilibrium temperatures at this hole suggest approximately 1,100 feet of permafrost (below 0°C). However, it is not unlikely that if the warming effect of the river and the nearby lake were removed the depth of the 0°C isotherm might approximate 1,300 feet.

The inverse geothermal gradient is about 100 feet per 1°C in the upper part of this well. If this inverse gradient is projected to the bottom of the hole, a bottom temperature of +95°C would be indicated. A temperature of 86.7°C at 9,788 feet was reported on the Schlumberger log of the well. A downward projection of the inverse gradient would indicate a temperature of approximately 87°C at 9,788 feet. Too much significance should not be attached to the comparison, however, as the Schlumberger bottom-hole temperature measurements made at various depths during drilling do not indicate the presence of a uniform geothermal gradient.

EAST TOPAGORUK TEST WELL 1

Location: Lat. 70°34′37.5″ N., long 155°22′39″ W.
Elevation: Ground, 50 feet; kelly bushing, 67 feet.
Spudded: February 18, 1951.
Completed: April 16, 1951.
Total depth: 3,589 feet; dry and abandoned.

The presence of suitable reservoir rocks in the sandstone beds of the Grandstand formation was demonstrated by Topogoruk test well 1, but no structural feature is present to trap oil at that site. Twelve miles to the east, however, reflection-seismograph surveys by party 147 of the United Geophysical Co., Inc., in 1950 located an anticline which has approximately 100 feet of closure over an area of 7,500 acres (fig. 16). Pre-Cretaceous rocks show no closure in this area, and East Topagoruk test well 1 was planned as a Cretaceous test to determine the fluid content of the permeable sandstone. The sandstone cored was too friable for permeability tests, but two sandstone samples had an effective porosity of 24 percent. Nevertheless, there were no shows of oil and only minor shows of gas in the hole; slightly gas-cut brackish water was recovered by a formation test.

STRATIGRAPHY

GUBIK FORMATION

The Gubik formation of Pleistocene age consists of about 75 feet of clay, sand, and gravel and contains bodies of ice. This formation is present in the test well from ground level (17 feet below the kelly bushing) to approximately 90 feet. Both the sand and the gravel are composed of very well-rounded clear, white, and yellow quartz and yellow, orange, and black chert. A few calcareous Foraminifera and Ostracoda are present; the Foraminifera are typical of Arctic shallow-water marine deposits of Pleistocene age.

GRANDSTAND FORMATION

This formation of Early Cretaceous age, present between 90 feet and 1,750 feet in the test well, consists of about 1,650 feet of sandstone with some interbedded shale. The medium-light-gray sandstone beds are massive and 10–100 feet thick; they are separated by 2- to 70-foot-thick beds of clay shale and siltstone with shaly cleavage. The sand grains are very fine subangular to subrounded clear and white quartz with some gray chert and rock fragments. Scattered grains of pyrite, mica, and coal are also present. Interstitial material is mostly silt or clay although a few beds have calcareous cement. The sand is poorly indurated, and the rock was too friable for air permeability tests; effective porosity is about 24 percent.

No shows of oil and only slight shows of gas were found although the sands are suitable reservoir rocks.

The clay shale and claystone are medium light gray to medium gray, slightly silty, and micaceous; they differ from each other only in the presence or absence of shaly cleavage. They commonly contain fragments of carbonized plants and carbonaceous particles. Laminae of silt in some of the clay shale beds show slight crossbedding. Some claystone in the first core (200–210 ft) is bentonitic. A minor amount of dense, hard, yellowish-gray clay ironstone and dense dark-gray argillaceous limestone is also present in the upper few hundred feet of the formation. A thin bed of coal near the top of the formation represents a thin nonmarine tongue within this essentially marine sequence. Both Grandstand and Topagoruk formations are flat lying.

TOPAGORUK FORMATION

The Topagoruk formation of Early Cretaceous age, penetrated from 1,750 feet to the bottom of the hole at 3,589 feet, consists of clay shale with some interbedded sandstone. The clay shale is medium to medium dark gray and commonly silty and micaceous and has fair to good bedding-plane cleavage. It contains laminae, streaks, and thin beds of medium-gray siltstone, which are crossbedded in some cores. Carbonaceous particles are scattered through much of the siltstone and shale; pyrite is present, though rare, in the upper part of the formation.

The sandstone is similar to that of the overlying Grandstand formation, but it is siltier and more argillaceous and, except for a 50-foot-thick bed at 2,220–2,270 feet, is present only in thin beds (2–10 ft thick) totaling about 5 percent of the rock. The upper part of the formation contains the best developed *Verneuilinoides borealis* fauna in the test well (H. R. Bergquist, personal communication).

DESCRIPTION OF CORES AND CUTTINGS

Lithologic description

[Where no cores are listed, description is based on cutting samples

Core	Depth (feet)	Description
----	0–17	Kelly bushing to ground level.
----	17–40	No samples received.
----	40–90	Sand, dusky-yellow, medium- to fine-grained; composed of very well-rounded to rounded grains of clear quartz, many having a yellowish cast; some white, yellow, and a few orange quartz grains and yellow, orange, and black chert.
----	90–92	No sample.
----	92	Gravel of chert granules, brown and black, well-rounded. Two pieces dark-gray dense argillaceous limestone. Sample taken from bit. Top of Grandstand formation at about 90 feet.
----	92–100	No sample.

Lithologic description—Continued

Core	Depth (feet)	Description
----	100	Coal, black, dull to vitreous, with blocky to irregular fracture. Sample taken from pump.
----	100–123	Clay ironstone fragments, coal, and sand as above. Clay ironstone is yellowish gray to grayish yellow and grayish orange, hard, with conchoidal fracture; some fragments react with hydrochloric acid. Sand is contamination from above.
----	123–130	No sample.
----	130–1, 140	Note: The cuttings taken above casing (set when hole was 1,140 ft deep), are described together here because they do not represent depths at which they were taken, and therefore have not been described in detail. Truer picture of sequence may be obtained from electric log, which suggests alternating shale and sandstone. Very calcareous sandstone present in ditch samples below 920 ft may be responsible for "kick" in log between 950 and 960 ft. Ditch samples above the 10¾-in. casing set at 1,100 ft (set when the hole was 1,140 ft deep) contain sand and gravel of Gubik formation, dense dark-gray argillaceous limestone, and hard grayish-yellow clay ironstone, with a minor amount of coal, rare pyrite (as small grains or concretions), and some sand and sandstone of Cretaceous age. Sandstone is very fine grained, composed of subangular to subrounded white and clear quartz, with some gray chert and rock fragments. Some is slightly calcareous to very calcareous. As rig was not equipped with mud screen or mud ditch, these samples are all badly contaminated and represent all the well-indurated rocks from above.
1	200–210	Recovered 3 ft: Microfossils absent. 8 in., claystone, light-medium-gray, bentonitic, with patches of white clay specks in waxy gray clay matrix. Biotite and muscovite flakes and carbonaceous particles common. 2 ft 2 in., claystone, medium-gray, noncalcareous, slightly bentonitic, with irregular fracture. Fragments of carbonized plants scattered throughout.
2	540–547	Recovered 7 ft: Microfossils common. Clay shale, medium-light-gray, noncalcareous, slightly micaceous (muscovite), with poor bedding-plane cleavage. Scattered carbonaceous particles present. Beds lie approximately flat.
3	800–810	Recovered 10 ft: Microfossils absent. Sandstone, medium-light-gray, very fine-grained, silty, argillaceous, with some fine to medium grains; some very slightly calcareous. Sand grains subround to subangular clear and white quartz, with very small amount of gray chert, mica, dark rock fragments, and pyrite. One doubly terminated quartz crystal found. Effective porosity 24.9 percent; sample too friable for air permeability test.
4	1, 100–1, 110	Recovered 10 ft: Microfossils abundant. Note: Core disturbed during handling en route to laboratory. Details of straitigraphic sequence therefore unknown. Interbedded clay shale, medium-light- to medium-gray, micaceous, noncalcareous, with poor bedding-plane cleavage suggesting that beds lie flat; and medium-light-gray fine-to very fine-grained silty argillaceous noncalcareous sandstone, with grains angular to subrounded, composed of clear quartz with some white quartz, gray chert, and dark rock fragments. Sandstone beds are 2–7 in. thick and total 20 percent of core. Pelecypod shell fragments in shale.
----	1, 140–1, 310	Sandstone, very fine-grained, poorly indurated, silty, argillaceous, partly calcareous, composed of subangular to subrounded white and clear quartz grains, with minor amount of gray chert and dark rock fragments. Mica, pyrite, and coal fragments very rare. Thin beds of siltstone and clay shale at 1,260–1,270 ft. Note: Sidewall cores 1–14 were taken at 1,170–1,230 feet. All but no. 4, which is of drilling mud, are light-gray sandstone, grading from fine- to very fine-grained with increasing depth and composed predominantly of white and clear quartz, with some dark grains and a small amount of lignite and coal.
----	1, 310–1, 400	Sandstone as above, with interbedded siltstone, similar in composition to the sandstone, and with medium-light-gray clay shale.

Lithologic description—Continued

Core	Depth (feet)	Description
5	1, 400–1, 410	Recovered 10 ft: Microfossils very rare. 7 in., sandstone, light-olive-gray, fine- to medium-grained, argillaceous, calcareous, poorly indurated; badly infiltrated with drilling mud. Grains subangular to subrounded white and clear quartz, gray chert, and dark rock fragments, with carbonaceous particles and very rare flakes of muscovite. 4 ft 8 in., clay shale, light-olive-gray, noncalcareous, with laminae of silt and sandy silt, showing slight crossbedding (dips less than 5°). A 2-in. bed of hard, dense medium-gray argillaceous limestone at 1,405 ft. 1 ft 11 in., sandstone as above; grayish-yellow one-half-in. clay ironstone bed at 1,406 ft. 5 in., clay shale, light-olive-gray, very calcareous, with subconchoidal fracture. 2 ft 3 in., alternating 3–4-in. beds of light-olive-gray silty clay shale and siltstone and medium- to fine-grained silty calcareous sandstone as above; section badly infiltrated with drilling mud. 2 in., clay shale, light-olive-gray, very calcareous, with subconchoidal fracture.
----	1, 410–1, 500	Interbedded sandstone, siltstone, and clay shale.
----	1, 500–1, 540	Sandstone, very fine-grained, with rare streaks of siltstone and clay shale.
----	1, 540–1, 710	Clay shale, with beds of sandstone and siltstone 2–10 ft thick, totaling approximately one-third of the rock.
----	1, 710–1, 720	Limestone, light-olive-gray, very arenaceous.
----	1, 720–1, 730	Siltstone and clay shale.
	1, 730–1, 731	No sample.
6	1, 731–1, 748	Recovered 17 ft: Microfossils very abundant. 4 ft 3 in., siltstone, medium-light-gray, very sandy, slightly argillaceous, very micaceous (muscovite), noncalcareous. Grains predominantly subangular clear and white quartz. Slightly darker laminae, some crossbedded, dip as much as 15°. Effective porosity at 1,735 ft 24 percent; sample too friable for air permeability test. ½ in., clay shale, medium-gray, with abundant worm (*Ditrupa* sp.) tubes and pelecypod (*Inoceramus* sp.) shell fragments. 7 in., clay shale, medium-gray, noncalcareous, micaceous on some partings. 4 in., siltstone as above but with biotite as well as muscovite. 1 ft 7 in., clay shale as above but slightly silty on some bedding planes and with rare thin beds and laminae (as much as 1 cm thick) of siltstone. Dip less than 4°. 7 in., siltstone, very sandy, as above. 11 in., clay shale as above, but with flakes of carbonized plants on some partings. 3 ft 3 in., siltstone as above, with rare beds of clay shale (up to 3 in. thick) as above. Grades into unit below. 5 ft 6 in., interbedded siltstone and clay shale; individual beds ½–8 in. thick, with shale increasing with depth. No oil odor, cut, or stain. *Inoceramus* sp. at 1,731–1,748 ft.
----	1, 748–1, 750	No sample.
----	1, 750–1, 790	Interbedded clay shale and siltstone with shaly cleavage, former increasing with depth. Top of Topagoruk formation at 1,750 feet.
----	1, 790–2, 000	Clay shale, medium-gray, very slightly micaceous, noncalcareous, with thin limestone beds at 1,815 and 1,887 ft.
7	2, 000–2, 016	Recovered 4 ft: Microfossils very abundant. Clay shale, medium-dark-gray, very slightly micaceous, noncalcareous, with poor bedding-plane cleavage.
8	2, 016–2, 032	Recovered 16 ft: Microfossils very abundant. Clay shale, medium-dark-gray, very slightly micaceous, noncalcareous. Beds probably lie flat, but bedding-plane cleavage is too poor to permit accurate dip measurements. *Inoceramus* sp. and *Ditrupa* sp. fragments present.
9	2, 032–2, 050	Recovered 18 ft: Microfossils very abundant. Clay shale as above, but slightly more silty. Laminae and beds (as much as 3 in. thick) of very argillaceous medium-light-gray siltstone with shaly cleavage make up about 10 percent of core. Beds faintly crossbedded, dip 5° or less. Upper 6 ft 6 in. badly infiltrated with drilling mud.

Lithologic description—Continued

Core	Depth (feet)	Description
10	2, 050–2, 070	Recovered 19 ft: Microfossils very abundant. Clay shale with thin beds of siltstone with shaly cleavage as in core 9, but some shale partings more coarsely micaceous than in cores above. Beds lie flat.
11	2, 070–2, 083	Recovered 10 ft: Microfossils very abundant. Clay shale with thin beds of siltstone with shaly cleavage as above. One siltstone bed at 2,072 ft crossbedded, with dip of 10°.
12	2, 083–2, 103	Recovered 19 ft: Microfossils very abundant. Clay shale, medium-gray, slightly calcareous to noncalcareous, micaceous on some partings. Some thin beds and laminae silty, medium light gray, slightly calcareous. Bedding-plane cleavage poor, but beds appear to lie flat. Some partings marked by flakes of carbonized plants. Pelecypod shell (*Nucula* sp. indet.) at 2,087 ft.
13	2, 103–2, 122	Recovered 19 ft: Microfossils very abundant. Clay shale as above; poor bedding-plane cleavage suggests beds lie flat; pelecypod shell at 2,110 ft.
14	2, 122–2, 132	Recovered 10 ft: Microfossils very abundant. Clay shale as above, but with less mica and silt. Pyritic concretion at 2,124 ft. Beds lie flat.
15	2, 132–2, 134	Recovered 2 ft: Microfossils very abundant. Clay shale as above.
16	2, 134–2, 144	Recovered 6 ft: Microfossils very abundant. Clay shale as above.
17	2, 144–2, 164	Recovered 18 ft: Microfossils very abundant. 1 ft 2 in., clay shale as above. 7 in., claystone, medium-gray, very silty, micaceous, noncalcareous; grades into unit below. 2 ft 7 in., siltstone, medium-light-gray, partly very carbonaceous, micaceous, noncalcareous; some small patches and laminae of medium-gray clay and streaks of sandy and micaceous siltstone; some crossbedding. 1 ft 2 in., clay shale as in core 12 above. 3 in., siltstone, medium-light-gray, with very micaceous, slightly sandy partings; crossbedded; shaly cleavage. 4 in., limestone, light-olive-gray, very argillaceous, dense, with a quarter inch of dark-gray very calcareous shale at top. 3 in., siltstone, medium-light-gray, slightly calcareous, with shaly cleavage, and micaceous and carbonaceous partings. 7 in., clay shale as above. 4 in., siltstone with shaly cleavage, as above. 5 in., clay shale as above. 2 ft, siltstone with shaly cleavage as above and 2-in. clay shale bed 6 inches below top of section. 8 ft 4 in., interbedded siltstone with shaly cleavage and clay shale as described above; commonly gradational. Individual beds range in thickness from lamina to 3 or 4 in. Beds lie flat.
18	2, 164–2, 184	Recovered 19 ft: Microfossils very abundant. Clay shale, medium-gray, rarely micaceous, commonly slightly calcareous. Thin beds, laminae, and partings of siltstone with shaly cleavage, usually containing carbonaceous flakes, are common in upper 5 ft, rare in lower 14 ft. Beds lie flat.
----	2, 184–2, 210	Clay shale as in core 18 above.
----	2, 210–2, 221	No sample received.
19	2, 221–2, 231	Recovered 7 ft: Microfossils absent. Core badly broken and infiltrated with drilling mud; color and reaction to hydrochloric acid may be affected by the drilling fluid. 2 ft, drilling mud with small fragments of sandstone as described below. 5 ft, sandstone, light-olive-gray, fine-grained, silty, very calcareous, poorly indurated. Fragments of salt-and-pepper sandstone near bottom of core are medium-gray, more indurated, and less calcareous than sandstone above. Sand grains subangular to subround, and composed of clear and white quartz, gray chert, and dark rock fragments in almost equal proportions. Some yellowish grains also present. Coal particles common; biotite rare; pyrite absent.

Lithologic description—Continued

Core	Depth (feet)	Description
20	2, 231-2, 251	Recovered 19 ft: Microfossils absent. Sandstone as above; upper 1 ft 9 in. very calcareous, very well indurated; remainder of core slightly calcareous and soft, with thin streaks and beds of more calcareous, more indurated material. No oil odor, stain, or cut. Formation test from 2,216 to 2,256 ft recovered no oil, a slight blow of gas, and brackish water. (See p. 307 for details.)
----	2, 251-3, 560	Note: The samples between cores 21-29 are described together here because they do not represent an accurate picture of this section; they imply a sand section with minor amounts of shale, whereas the electric and driller's logs indicate a shale section with some sandstone beds. The concentrations of shale and sandstone fragments in the cuttings rarely coincide with the occurrence of those rocks as indicated by the logs. Consequently, as in the depths from 130 to 1,140 ft, the electric log is considered to give a more dependable picture of the material penetrated. Ditch samples from 2,251 to 3,560 ft consist largely of loose sand composed of angular to subrounded clear and white commonly frosted quartz, and gray chert, with rare dark rock fragments. Pyrite and carbonaceous particles common throughout. Sandstone fragments constitute 5-10 percent of samples from 2,251 to 2,340 ft, and 2,390 to 2,410 ft; 15 percent from 2,440 to 2,470 ft; 70 percent from 2,540 to 2,550 ft; and 5-15 percent in half the samples from 2,830 to 2,920 ft; most samples contain 5-15 percent from 3,070 to 3,560 ft. Elsewhere they are rare or absent. Many samples throughout section contain 5-10 percent medium-light-gray micaceous siltstone. Fragments of medium-gray micaceous slightly silty clay shale form only a minor part (5-15 percent) of most samples, though they constitute 50-80 percent of the material in samples from 2,350 to 2,430 ft and 20-70 percent (increasing with depth) from 3,360 to 3,560 ft. Two crinoid columnals found at 3,427-3,430 ft.
21	2, 485-2, 505	Recovered 5 ft: Microfossils very abundant. 3 ft 3 in., clay shale, medium-gray, noncalcareous; tends to hackly cleavage; bedding flat. 2 in., siltstone, light-gray, very finely micaceous, noncalcareous, hard; shaley cleavage. 1 ft 3 in., clay shale, as above, but with numerous carbonaceous flakes. 2 in., siltstone, as above. 2 in., clay shale, as above, with carbonaceous flakes.
22	2, 505-2, 507	No recovery.
23	2, 800-2, 820	Recovered 17 ft: Microfossils common. Clay shale, medium- to medium-dark-gray, very finely and sparsely micaceous; rare silty partings; breaks easily along irregular surfaces parallel to bedding. Beds lie approximately flat.
24	3, 000-3, 013	Recovered 10 ft: Microfossils abundant. Clay shale, medium-gray, noncalcareous; tends to hackly cleavage; rare silty slightly calcareous finely micaceous partings.
25	3, 013-3, 033	Recovered 20 ft: Microfossils abundant. Clay shale, medium-gray, noncalcareous, with rare carbonaceous fragments; tends to hackly cleavage parallel to bedding; sporadic silty partings and rare thin laminae (up to 1 in.) of silt as above. Beds lie approximately flat.
26	3, 033-3, 053	Recovered 17 ft: Not sampled for microfossils. Clay shale, as above.
27	3, 053-3, 056	Recovered 3 ft: Microfossils very abundant. Clay shale, as above.
28	3, 056-3, 076	Recovered 20 ft: Microfossils very abundant. 1 ft 10 in., clay shale, as above. 2 ft 4 in., siltstone, medium-light-gray, sparsely and finely micaceous, noncalcareous: bedding not obvious. Thin laminae and small irregularly shaped inclusions of clay shale, as above. 15 ft 10 in., clay shale, as above. Dip less than 10° in crossbedded siltstone laminae. Beds lie flat otherwise.
29	3, 407-3, 426	Recovered 4 ft: Microfossils abundant. Clay shale, as in cores above; beds lie flat.
----	3, 560-3, 569	No sample received.
30	3, 569-3, 589	Recovered 20 ft: Microfossils very rare. Clay shale, as above, with partings and irregular lenticular laminae of medium-light-gray finely micaceous slightly calcareous siltstone; crossbedding well developed in silty sequences; dip (believed to be on true bedding planes) 8°-14° and generally about 10°.
	3,589.	Total depth

HEAVY-MINERAL ANALYSIS

Preparation of samples and criteria used in delimiting zones are the same as in Topagoruk test well 1. Robert H. Morris has determined that two heavy-mineral zones are recognized in East Topagoruk test well 1, the glaucophane zone and the zoned zircon zone. (See fig. 17.) The glaucophane zone is present from 800 feet to 1,410 feet. The zircon zone is represented by one sample at 2,231 feet.

CORE ANALYSIS

The effective porosity of the two sandstones cored was determined by the Barnes method. The rock was too friable for air permeability tests with the available equipment. Effective porosity of sandstone from core 3, at 800–810 feet, is 24.9 percent; it is 24.0 percent at 1,735 feet in core 6.

OIL AND GAS

OIL AND GAS SHOWS

There were no shows of oil, and no commercial shows of gas in the hole; a slight amount of gas-cut mud, from a formation test at 2,216–2,254 feet was the only evidence of hydrocarbons in the hole.

FORMATION TEST

A formation test was made between 2,216 and 2,254 feet to see whether any fluid was present in the rock and, if so, whether it could be produced. The following was obtained from the Arctic Contractors (written communication, 1951):

Set Johnston Formation Tester with 8 ⅝-inch open-hole sidewall packer in 9 ⅝-inch hole at 2,216 feet, using ⅜-inch bean. Length of tail pipe was 36 feet. The perforated interval covered from 2,225 to 2,250 feet. Two pressure recorders were on the bottom of the tail pipe from 2,250 to 2,256 feet. The tester was left open 33 minutes. Had a weak blow throughout the entire period. The test was then closed in for 15 minutes; 1,880 feet of fluid was recovered. The upper part was gas-cut drilling mud, the middle (930 ft) was gassy muddy water, and the bottom (80 ft), gassy brackish water. The salinity of the upper part was 116 grains per gallon; the middle, 460 grains per gallon; and the bottom, 525 grains per gallon. When the trip valve was opened, the pressure dropped to 410 pounds per square inch, and then built up to 830 pounds per square inch under flowing condition. During the closed-in period the pressure jumped to 950 pounds per square inch. The bottom hole temperature was 89° F.

LOGISTICS

Personnel and housing.—The supervisory staff was made up of 1 drilling foreman, 1 petroleum engineer, and 1 geologist. The rig crew consisted of 2 drillers, 2 derrickmen, 6 floormen, 2 firemen, 2 heavy-duty-equipment mechanics, and 1 oiler. One oil-field warehouseman-timekeeper-storekeeper, 2 cooks, 1 kitchen helper, and 2 bulldozer operators were also employed. All temporary personnel (carpenters, electricians, cementers, and Schlumberger operators) were sent from the Barrow camp as needed. Twenty wanigans were used for housing, shops, office, and storage at the drilling site.

Vehicles and heavy equipment.—The 1,100 tons of supplies and equipment used in drilling the hole were hauled to the test-well site on tractor trains. Vehicles used at the well were 2 weasels, 1 TD9 crane, 1 D8 bulldozer, and 1 swing crane. The following were the major items of equipment used by Arctic Contractors:

1--Ideco derrick (87- by 24-ft base) with racking platform and finger.
1--Cardwell drawworks (model H) with Foster Hi-speed cathead and rotary drive.
1--Caterpillar D8800 diesel engine on drawworks.
1--Ideal crown block, model D-12 with 34-in. sheaves.
1--Ideal traveling block, model D, with 34-in. sheaves grooved for 1-in. line.
1--Ideal swivel, model D.
1--Byron-Jackson 125-ton Triplex hook.
2--Gardner-Denver circulating pumps model FXO, 7½ x 10 in.
2--Caterpillar D13000 diesel engines for circulating pumps.
1--Marlow cellar pump (model 445) powered by 5-hp United States electric motor.
1--Mud tank with dividing partition (total capacity, 121½ bbl).
1--Kewanee 35-hp boiler, 110 psi steam pressure.
1--Shaffer blowout preventer.

Fuel, water, and lubricant consumption.—The following amounts of fuel were used: 50,284 gallons of diesel fuel, 4,007 gallons of 72-octane gasoline, and 159 gallons of 65-octane gasoline. Water consumption was 449,500 gallons; lubricating compounds consumed totaled 90 pounds of grease, 310 pounds of thread lubricant, and 632 gallons of general lubricant.

DRILLING OPERATIONS

East Topagoruk test well 1 was drilled with a Cardwell no. 1 rotary rig. The derrick and drawworks were mounted on a steel substructure mounted on heavy steel sled runners for transport over the frozen terrain. A summary of the drilling operations is given below:

Depth (feet)	*Remarks*
109	Cemented 109 ft of 13⅜-in. casing with 200 sacks CalSeal, 60 sacks portland cement.
1,410	Cemented 1,100 ft of 10¾-in. casing with 201 sacks portland cement. Installed Shaffer blowout preventer and flow line.
2,256	Johnston formation test, 2,216–2,256 ft.
2,485	Drill pipe stuck at 2,218 ft, while coming out of hole. Spotted oil and recovered pipe by backing off (top fish at 1,873 ft), washing over, and cutting.

3,589-------- Took 14 sidewall cores, 1,170–1,230 ft. Cemented plug at 1,120 ft with 25 sacks portland cement treated with 6 percent CalSeal. Top of plug 1,049 ft. Bailed 10¾-in. casing dry to 1,049 ft to determine effect of permafrost on casing. Removed Shaffer blowout preventer. Welded 10¾-in. riser to top of 10¾-in. casing, which is about 18 in. above ground level.

DRILL AND CORE BITS

Nineteen drill bits, in five sizes (from 8¾ to 20 in.) were used in drilling East Topagoruk test well 1; they included a 20-inch hole opener and a 17½-inch bit to drill the hole for the 109 feet of surface casing. The bits generally showed very little wear on the teeth. The coring was done with Reed wire line or conventional core barrels. Coring with the wire line core barrel was done with an 8¾-inch hard-formation core head, whereas 6⅛-inch hard-formation and soft-formation core heads were used on the conventional core barrel. The footage cored was 433 feet, with a recovery of 369 feet.

DRILLING MUD

The hole was spudded with a 64.5 pound per cubic foot Aquagel-water mud. The viscosity and gel strength of the mud had to be increased because large quantities of sand and silt being penetrated settled out; consequently, enough Aquagel and Baroid were added to give a viscosity of 70 Marsh funnel seconds and a weight of 85 pounds per cubic foot. The sand content was quite high—about 15–20 percent.

At 150 feet bentonitic and clayey shales were found, and water was added in an attempt to drop the entrained sand and to reduce the viscosity. By treating with water, tetrasodium pyrophosphate, and quebracho, the average mud characteristics down to the bottom of the surface casing at 1,100 feet were—

Weight: 85 lb per cu ft.
Viscosity: 42 Marsh funnel sec.
Water loss: 7.0 cu cm per 30 min.
Cake: 3/32 in.
Gel strength: 0 at first test, and after 10 min.
Sand strength: 10 percent.
pH: 8.

The following description was obtained from Arctic Contractors (written communication, 1951):

Upon drilling out the cement, the mud showed a fairly high degree of contamination. Quebracho and sodium bicarbonate were used to restore the mud to its original character. From 1,100 feet to the bottom at 3,589 feet the sand content was reduced from 10 percent to approximately 0.5 percent.

When the drill pipe became stuck at 2,215 feet, 50 drums of 20 gravity crude oil were introduced into the mud system and resulted in raising the viscosity to about 75 Marsh funnel seconds. By treating with water and quebracho the viscosity was reduced to an average of 55 Marsh funnel seconds and held at this value. Baroid was added to make up the loss in weight occasioned by gas and oil in the system. The presence of the crude oil in the mud appeared to be very beneficial in lowering the water loss by emulsification. The average water loss after the addition of the oil was 2.8 cc per 30 minutes. It was found that barring contaminants the treating of the mud could be carried on almost entirely with appropriate additions of water, quebracho, and tetrasodium pyrophosphate. The quebracho was found to be more efficient as a thinning agent than the sodium pyrophosphate and also in its water-loss reducing ability.

The following table gives the pertinent information about drilling-mud characteristics and additives at East Topagoruk test well 1.

Drilling-mud characteristics and additives, East Topagoruk test well 1

Depth (ft)	Weight (lbs/cu ft)	Viscosity (API sec)	Filtration loss (cc 30 min)	Additives
45	65	55	3.5	
95	80	60	----------	106 sacks Aquagel, 27 sacks Baroid.
110	78	59	3.5	
220	83	50	12.5	
540	86	44	10.0	
660	83	35	9.5	
809	87	40	9.5	72 lb quebracho, 114 lb tetrasodium pyrophosphate.
945	88	41	8.0	
1,062	89	44	6.5	
1,100	86	38	7.0	
1,185	83	44	7.0	
1,400	85	44	5.0	14 sacks Aquagel, 150 lb tetrasodium pyrophosphate, 24 lb quebracho.
1,410	86	----------	4.5	
1,570	76	36	11.0	
1,731	80	37	9.0	
1,857	82	36	5.0	250 lb quebracho, 20 lb tetrasodium pyrophosphate, 72 lb sodium bicarbonate, 6 sacks Aquagel.
1,986	85	42	5.0	
2,016	85	46	4.5	
2,050	83	38	3.5	
2,083	84	41	3.0	
2,100	85	37	4.0	
2,160	83	40	3.5	
2,175	79	39	4.0	
2,220	85	39	3.5	
2,250	85	40	3.5	
2,256	85	40	3.5	
2,356	80	37	4.0	
2,485	84	39	3.5	
2,560	85	60	3.0	11 sacks Aquagel, 100 lb quebracho, 24 sacks Baroid, 50 drums crude oil.
2,773	85	57	3.0	
2,889	86	54	3.0	
3,013	87	57	3.0	18 lb tetrasodium pyrophosphate.
3,056	86	52	3.0	
3,136	88	51	2.5	
3,284	87	48	2.7	
3,410	89	46	3.0	
3,445	89	52	3.0	
3,569	89	51	3.0	
3,589	88	53	3.0	

HOLE DEVIATION

The first thousand feet of the hole was essentially vertical; the second thousand feet had a deviation of 15–20 minutes, and below 2,000 feet the hole was 20–30 minutes from vertical, as measured with the Totco recorder.

ELECTRIC LOGGING

One Widco and three Schlumberger electric logs were run. The results, except for 1,000 feet of run 4 that overlapped run 3, are shown on the graphic log (pl. 18). The Widco log, run 1, was made between 109 and 1,098 feet; the Schlumberger logs (runs 2, 3, and 4) were made at 1,100–2,250 feet, 2,250–3,402 feet, and at 3,300–3,586 feet, respectively. No other types of logs were run.

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MICROPALEONTOLOGIC STUDY OF THE TOPAGORUK TEST WELLS, NORTHERN ALASKA

By Harlan R. Bergquist

During the drilling of test wells in the Topagoruk area several thousand feet of sedimentary rocks of Mesozoic and Paleozoic age were penetrated. In East Topagoruk test well 1 a section of about 3,500 feet of Lower Cretaceous strata was drilled, but in Topagoruk test well 1 the section of Lower Cretaceous rocks penetrated was 6,550 feet thick. Beneath this thicker section are 2,040 feet of Jurassic strata, and approximately 1,123 feet of beds of Permian and Devonian age. Most of the formations of Mesozoic age were identified by study of the microfossils, but the age of the Middle Jurassic strata was determined with ammonites studied by Ralph W. Imlay, and the Devonian strata were identified as such by James Schopf, who studied primitive plants found in some of the cores.

About 750 core and ditch samples from Topagoruk test well 1 and East Topagoruk test well 1 were processed in the Geological Survey at Fairbanks and studied for microfossils. Most of the Foraminifera found in these samples came from the *Verneuilinoides borealis* faunal zone. This faunal zone can be traced in the subsurface over much of northern Alaska and embraces a Lower Cretaceous section of Albian age that is from 2,000 to 3,000 feet thick. It is in the wells in the Topagoruk area, however, that the best development of the *V. borealis* zone occurs, as over 50 species of Foraminifera and a few species of Radiolaria were found, although many of the species are represented by only 1 or 2 specimens.

The sandy part of the section that Florence Collins has assigned to the Grandstand formation in Topagoruk test well 1 yielded 18 species of Foraminifera. Of these *Verneuilinoides borealis* Tappan was common, and the rest were relatively rare, except for one common occurrence of each of the following: *Miliammina awunensis* Tappan, *Spiroloculina ophionea* Loeblich and Tappan, and *Ammobaculites* n. sp. In East Topagoruk test well 1, 24 species were recorded from the sandy beds in the upper part of the *Verneuilinoides borealis* zone. Each of these species was relatively rare except for *V. borealis*, but in one sample *Miliammina awunensis* was common. In both wells *Inoceramus* prisms and *Ditrupa* sp. were found in the upper part of the *Verneuilinoides borealis* zone.

In both wells many more Foraminifera were found in the shale section in the lower part of the *Verneuilinoides borealis* zone than in the sandy portion, owing perhaps to the greater thickness of the shale section. In Topagoruk test well 1 there occurred in the shale section (1,350–3,900 feet) at least 35 more species than were found in the overlying sandy beds (50–1,350 feet); in East Topagoruk test well 1, 31 more species were found in the shale section (1,750 feet to total depth) than in the overlying sandy beds (80–1,750 feet). *Verneuilinoides borealis* continued in abundance throughout the *Verneuilinoides borealis* zone of each well, but specimens of *Haplophragmoides topagorukensis* Tappan, *Bathysiphon vitta* Nauss, and *Gavelinella stictata* (Tappan) greatly increased in numbers in the shale sections. Of these species *H. topagorukensis* was by far the most abundant and most frequent in occurrence.

Twenty-four species of Foraminifera were found in a core sample from 1,490–1,501 feet in Topagoruk test well 1. This was the most fossiliferous core taken from the *Verneuilinoides borealis* zone. Very fossiliferous samples came from cores at 2,032–2,042 feet and at 2,165–2,174 feet in East Topagoruk test well 1, but these are within a cored section from 2,012–2,184 feet which had a greater concentration of Foraminifera than found in any equivalent thickness of beds in the well. Below this interval of numerous fossils, the number of specimens decreased, and only specimens of *Bathysiphon vitta* and *Haplophragmoides topagorukensis* were strongly persistent. However, 7 species were found in each of the three lower cores (3,053–3,076 ft).

Many of the Foraminifera found in the *Verneuilinoides borealis* faunal zone are new and have been described recently by Mrs. Helen Tappan Loeblich (Tappan, 1951, 1957), but several are the same as species known from Albian beds in Europe and western Canada.

Drilling of East Topagoruk test well 1 was abandoned in shale beds within the *Verneuilinoides borealis* faunal zone, but in Topagoruk test well 1 a section of 2,700 feet of dark shale was penetrated that seems to be correlative with beds in the type section of the Oumalik formation in Oumalik test well 1. Very few fossils were found in the cores, and fossils in the ditch samples came from the *Verneuilinoides borealis* beds as contamination. One pyritic cast of *Lithocampe?* sp., a radiolarian, is the only fossil of the Oumalik formation found in the well. The formation is indirectly inferred to be early Albian in age, as it seemingly correlates with the middle or lower part of the Torok formation, and this part of the section has been assigned an Albian age by Imlay (Imlay and Reeside, 1954).

Jurassic and Triassic strata in Topagoruk test well 1 were identified as such largely by the Foraminifera found in these sections. Information about the species is given below under the discussion of the well.

TOPAGORUK TEST WELL 1

PLEISTOCENE DEPOSITS

GUBIK FORMATION (14–50 FEET)

Pleistocene strata penetrated in this well were nonfossiliferous.

CRETACEOUS ROCKS

VERNEUILINOIDES BOREALIS FAUNAL ZONE (50–3,900 FEET)

The upper 460 feet of section of the Cretaceous rocks was almost unfossiliferous and only a relatively small fauna was found in most of the samples from the upper part of the *Verneuilinoides borealis* faunal zone. Of the 4 cores taken in the upper 1,200 feet in the zone, only 1 (911–919 ft) had fossils. In this core sample *Verneuilinoides borealis* Tappan was very abundant, and *Ammobaculites* n. sp., *Spiroloculina ophionea* Loeblich and Tappan, and *Miliammina awunensis* Tappan were common; a few specimens of *Gaudryina canadensis* Cushman and *Spiroplectammina koveri* Tappan occurred with them. Other than *V. borealis*, few Foraminifera were found in the ditch samples. *Ditrupa* sp. tubes [1] were in samples from 420–430 and 580–590 feet and in lower beds; *Inoceramus* prisms occurred in cores from 596–608 feet and 911–919 feet and in several ditch samples.

The most common species in the *Verneuilinoides borealis* zone are *Haplophragmoides topagorukensis* Tappan and *Verneuilinoids borealis*, which occurred in relative abundance in many of the samples. Third most numerous species is *Bathysiphon vitta* Nauss, and ranking fourth were specimens of *Gavelinella stictata* (Tappan).

Two cores had a large fauna that is very representative of the *V. borealis* faunal zone. In the sample from 1,490–1,501 feet, there were more than 20 species of Foraminifera, a few ostracodes, and fragments of *Inoceramus* shells and *Ditrupa* sp. tubes. Only a few specimens of *V. borealis* were in the sample although the species is usually common in the zone. *Haplophragmoides topagorukensis* and *Gavelinella stictata* were abundant in the core, and *Bathysiphon brosgei* Tappan, *B. vitta*, *Astacolus* sp., *Eurycheilostoma grandstandensis* Tappan, and *E. robinsonae* Tappan are common. Of rare occurrence are *Hyperamminoides barksdalei* Tappan, *Ammobaculites* n. sp., *Gaudryina canadensis?* Cushman, *Tritaxia manitobensis?* Wickenden, *Glomospirella gaultina* (Berthelin), *Spiroloculina ophionea*, *Miliammina manitobensis* Wickenden, *Lenticulina erecta* (Perner), *Globulina lacrima* Reuss, *Pallaimorphina ruckerae* Tappan, and a few other specimens identified only generically. In the other very fossiliferous core (2,390–2,399 ft), *Haplophragmoides topagorukensis* was abundant, whereas there were only rare occurrences of several of the species cited from the higher core.

Very few Foraminifera were found in the samples from other cores in the faunal zone. The small fauna in a core from 2,940–2,950 feet consisted predominantly of specimens of *Haplophragmoides topagorukensis* and *Bathysiphon vitta*. In a core from 3,550–3,560 feet, these two species were rare, and *Textularia topagorukensis* Tappan was common. A specimen of an ammonite found at 3,249 feet was identified by Ralph W. Imlay as *Cleoniceras* n. sp. Only a few specimens of Foraminifera occurred in the lowest core (3,804–3,807 ft) considered to be in the faunal zone.

A conspicuous but not numerically prominent foraminifer in the *Verneuilinoides borealis* zone is *Gaudryina nanushukensis* Tappan, which occurred in many ditch samples below 1,700 feet but was not found in any of the core samples. In ditch samples below 3,000 feet were many glaconitic casts of *Dictyomitra* sp. In a few samples the specimens were common.

OUMALIK FORMATION (3,900–6,600 FEET)

Ditch samples throughout the Oumalik formation carried specimens of the *V. borealis* fauna, but these were obviously introduced from the higher beds during drilling as shown by the fact that the fossiliferous ditch samples occurred above and below unfossiliferous cores throughout the formation. Most of the contamination occurred from the top of the formation to a depth of about 5,120 feet. One core from the formation contained two specimens of *Haplophragmoides topagorukensis*. *Inoceramus* prisms were in two other cores. The formation is identified, however, by the absence of the *V. borealis* fauna from the cores and the presence of pyritic casts of *Lithocampe?* sp., a radiolarian found in the Oumalik formation in the test wells on the Oumalik anticline. The casts of *Lithocampe?* sp. were scattered in samples from 4,610–5,200 feet.

[1] Curved tubular shells from the Cretaceous strata of northern Alaska were formerly referred to *Laevidentalium* sp. or *Dentalium* sp. Determinations by Ralph W. Imlay show that these are not scaphopods but are worm tubes of the genus Ditrupa.

JURASSIC ROCKS

UPPER JURASSIC ROCKS (6,600–7,820 FEET)

Most of the Jurassic species of Foraminifera identified in the Topagoruk test well were described by Mrs. Helen Tappan Loeblich (Tappan, 1955), who also determined the age of the beds as Oxfordian or Lower Kimmeridgian. Two species were common to abundant in a core from 6,743–6,753 feet, and some specimens occurred in most of the ditch samples. A core from 7,042–7,062 feet, however, had a prolific fauna of about 24 species of Foraminifera, which includes all species known in Upper Jurassic rocks in northern Alaska (Tappan, 1955). In order of abundance this fauna is as follows: Abundant specimens, *Ammobaculites alaskensis* Tappan and *Trochammina* sp.; common specimens, *Haplophragmoides canui* Tappan, *Gaudryina topagorukensis* Tappan, *Trochammina canningensis* Tappan, and *T. topagorukensis* Tappan; rare occurrences, *Bathysiphon anomalocoelia* Tappan, *Involutina orbis* (Lalicker), *Glomospira pattoni* Tappan, *Gaudryina* [redacted] *milleri* Tappan, *G. leffingwelli* Tappan, *Lenticulina wisniowskii* (Myatliuk), *Darbyella volgensis* Tappan, *Saracenaria oxfordiana* Tappan, *S. phaedra* Tappan, *S. topagorukensis* Tappan, *Marginulinopsis phragmites* Loeblich and Tappan, *Marginulina brevis* Paalzow, *M. pinguicula* Tappan, *Rectoglandulina brandi* Tappan, *Dentalina ectadia* Loeblich and Tappan, *Frondicularia* sp., *Lagena liasica* (Kübler and Zwingli), and *Globulina topagorukensis* Tappan. A pelecypod found at 7,060 feet was identified as *Aucella* cf. *A. rugosa* (Fischer) by R. W. Imlay.

MIDDLE JURASSIC ROCKS (7,820–8,640 FEET)

The age of these beds was determined by Imlay (1955, p. 82) from a few ammonites found in a core from 8,111–8,113 feet. No Foraminifera were in the cores from this section; the ditch samples carried Late Jurassic species, the result of drilling contamination.

TRIASSIC ROCKS

SHUBLIK FORMATION (8,640–9,380 FEET)

A few specimens of Triassic Foraminifera were found in ditch and core samples and were identified by comparison with the fauna described by Mrs. Helen Tappan Loeblich (Tappan, 1951) from the Triassic of northern Alaska. *Astacolus connudatus* Tappan and *Nodosaria shublikensis* Tappan were in ditch samples from 8,640–8,700 feet; in a core from 8,917–8,921 feet there were several specimens of *Bolivina lathetica* Tappan, a few pyritic casts of *Pyrulinoides plagia* Tappan, and a fragment of *Frondicularia acmaea* Tappan. Prints of two Triassic pelecypods, *Halobia* sp. and *Monotis* sp. were also in the core. The core from 9,200–9,202 feet was barren.

A mixed fauna of a few Triassic Foraminifera and Late Jurassic species (drilling contamination) was in the ditch samples, particularly in samples from 9,202–9,380 feet, where a number of Late Jurassic species were common to abundant. However, nearly every sample from within this depth range contained specimens of *Trochamminoides vertens* Tappan, a Triassic foraminifer, and 1 or 2 species of Triassic ostracodes.

PERMIAN ROCKS (9,380–9,770 FEET)

Ditch samples contained only Late Jurassic and Triassic microfossils, but these were contamination from higher beds. Cores were barren except for shells of *Lingula* sp. at 9,433–9,455 feet and 9,462–9,492 feet; tiny objects in a core from 9,438 feet were identified by D. H. Dunkle, of the United States National Museum, as coelocanth fish teeth of Permian age.

RED BEDS (9,770–10,040 FEET)

The cores taken in the red beds were nonfossiliferous, and although Foraminifera were found in ditch samples, all represented contamination from Upper Jurassic and Triassic strata.

LOWER(?) OR MIDDLE DEVONIAN STRATA (10,040–10,503 feet)

The few cores were unfossiliferous except one piece of core (from 10,441 ft) that had plant prints which James M. Schopf identified as primitive species restricted to Middle (or possibly Lower) Devonian strata. Ditch samples were barren except for those from 10,040–10,503 feet which contained Late Jurassic and Triassic Foraminifera that had been introduced by the circulating mud during drilling.

EAST TOPAGORUK TEST WELL 1

PLEISTOCENE DEPOSITS

GUBIK FORMATION (17–90 FEET)

No fossils were found in the samples from the Pleistocene deposits, but samples from Cretaceous strata contained a few specimens of Foraminifera typical of the Gubik formation that were probably introduced during drilling operations.

CRETACEOUS ROCKS

VERNEUILINOIDES BOREALIS FAUNAL ZONE (90 FEET TO TOTAL DEPTH)

Relatively few fossils occurred in the upper few hundred feet of section in this well but in the small fauna *Verneuilinoides borealis* was the most numerous and was common in three samples. *Miliammina awunensis* ranked second in frequency of occurrence. A few other species occurred sporadically through the section. Several specimens of *Haplophragmoides topagorukensis* and a few specimens of 2 or 3 species of calcareous Foraminifera were found in a core sample from 540–547 feet. Fragments of *Ditrupa* sp. tubes occurred at 820–830 feet and in several samples below 1,600 feet, where they were associated with *Inoceramus* prisms. Most ditch samples were barren below 600 feet, but a core sample from 1,100–1,110 feet had a fauna made up almost entirely of abundant *Haplophragmoides topagorukensis* and common specimens of *V. borealis*, with a few specimens of 4 or 5 other species. A lower core sample (1,738–1,748 ft) had abundant specimens of *V. borealis* and *Haplophragmoides topagorukensis* and a few specimens each of eight calcareous species of Foraminifera, of which, *Gavelinella stictata* and *Eurycheilostoma grandstandensis* were the most numerous.

Starting with the first sample in a continuously cored sequence, an abundant fauna was found in every sample from 2,012 feet through 2,184 feet. Between these depths the *V. borealis* fauna is well developed. *V. borealis* was common in many of the samples, and *Haplophragmoides topagorukensis* was abundant in even more of them. Fragments of *Bathysiphon vitta* were common to abundant in many samples, and *Gaudryina nanushukensis* was abundant from 2,113–2,144 feet. *Tritaxia manitobensis* was common in 2 samples; *Miliammina manitobensis* was common in 1. Specimens of *Involutina rotalaria* (Loeblich and Tappan) were abundant in a few samples and occurred in several others. Tests of *Gavelinella stictata* were abundant to common in a few samples and rare in several. *Eurycheilostoma grandstandensis* was very abundant in 2 samples, common in 1 sample, and rare in others. *Bathysiphon brosgei*, *Saccammina* sp., *Hyperamminoides barksdalei*, *Ammobaculites* n. sp., *Gaudryina canadensis*, *Lenticulina macrodisca* (Reuss), *Marginulina gatesi* Tappan, *M. planiuscula* (Reuss), *Globulina bucculenta* (Berthelin), *Eurycheilostoma robinsonae*, *Valvulineria loetterlei* (Tappan), *Globorotalites alaskensis* Tappan, and *Pallaimorphina ruckerae* are among the species which were found rather rarely in the samples. *Inoceramus* prisms and fragments of *Ditrupa* sp. tubes occurred in several samples.

Every ditch sample from 2,257 feet to the total depth of the well contained some Foraminifera, but only a few species occurred at many horizons or were abundant in contrast to the large number in the very fossiliferous core. Only *Haplophragmoides topagorukensis* was common to abundant in many of the samples. *Bathysiphon vitta* occurred in nearly every sample but was common in none. Other species occurred rarely. In core samples the fossil occurrence was about the same except that *Bathysiphon vitta* was common or abundant in two samples. The lowest occurrence of *Gaudryina nanushukensis* was in a sample from 3,053–3,056 feet. *Gavelinella stictata* was common in a core sample from 2,485–2,505 feet. Glauconitic casts of *Dictyomitra* sp. were abundant in a core from 3,066–3,076 feet. The lowest cores were barren.

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